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Notable
Achievements *of the*
Naval Weapons
Center

by R.E. Kistler and R.M. Glen
Naval Weapons Center, China Lake, California
August 1990

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Naval Weapons Center

FOREWORD

This report summarizes some of the achievements of the Naval Weapons Center from its inception in 1943 to its current continuing role in carrying out the complete weapon-development process from basic and applied research through Fleet and production support.

The report was assembled at the request of G. R. Schiefer, former NWC Technical Director, to provide more detailed information, particularly for Headquarters personnel, on the Center's achievements.

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3 July 1990

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INTRODUCTION

The Naval Weapons Center (NWC), China Lake, Calif., has an extraordinary record of achievement stretching over nearly 50 years. During his tenure as Secretary of Defense, Robert McNamara commented that China Lake "designed 85 percent of the Free World's air weapons." In extensive peer rating surveys conducted by the Office of the Chief of Naval Material in the 1970s, China Lake was rated the top Navy laboratory. Some years later David Packard, in his role as chairman of the Packard Commission, declared that China Lake "is one of the two or three best federal laboratories."

For security reasons the Center's accomplishments have not been widely publicized. Consequently neither the achievements of the Center nor the factors that have made NWC successful are widely known outside the immediate Navy research and development (R&D) community. This is true of other in-house Navy R&D laboratories as well, and may contribute to a perception that the in-house laboratories are not productive.

The fact is that because much of the work of the R&D laboratories is classified, these facilities tend to try to keep a "low profile" to minimize security problems. In addition, the complexity of many R&D efforts is such that the contributions of the in-house laboratories can become obscured. For example, the in-house laboratory may perform critical research and, on the basis of such research, may design a new weapon. The laboratory's role in full-scale engineering development of that weapon may be a key one, or even a dominant one. But by the time the weapon goes into production, the trade journals, Headquarters people, and even the Fleet users tend to associate it with the private-sector contractor that produces it. The technology that made the weapon possible gets merged into the identity of the weapon system, and recollection of where that technology originated is lost. Navy managers are frustrated to read and hear words to the effect that "the in-house laboratories do not produce much." NWC knows that its record of achievement over the years can match or exceed that of any R&D activity anywhere. Again, other in-house laboratories share this frustration in conveying the reality of what the laboratories have done and are doing.

The China Lake message should not be lost or forgotten—NWC's resources, geographic remoteness, land expanse; the fact that at NWC you can carry a development program all the way through from concept to all-up test and evaluation of the complete system, without leaving the China Lake complex; the willingness of the Navy to allow weapon development programs actually to be conducted under the technical direction of weapon experts at China Lake, rather than business managers in Headquarters. The China Lake outlook is not static; it is characterized by innovation, change, and responsible risk-taking.

This report is an overview of the way China Lake operates and how China Lake manages change. The discussion will not be limited to generalities about the work environment, but will deal specifically with the program management processes that have worked at China Lake and how these processes have evolved and continue to evolve. Major emphasis will be on how programs

are or should be carried out—contractual arrangements, interaction with other Navy entities, focus of responsibility, and other aspects of the management of weapon system development programs. Integral in this management is the close partnership between China Lake and the Systems Commands. The Systems Commands are the sponsors and also the innovators who have allowed—in fact, directed—the achievements recorded here.

This report discusses the facilities of the Center—the extensive land, airspace, and elaborate test and evaluation (T&E) facilities ("outdoor laboratories") that are the foundations of the concept of "doing everything under one roof," and the importance of this to the Center's long-running success story. The report highlights some of the Center's achievements, beginning with contributions that go back to World War II. Included are postwar rocket development work, and contributions of a quick-response nature to the wars in Korea and Vietnam. The appendix to this report describes some of the numerous weapons and other systems that have been designed here and ultimately delivered to the Fleet. A few of these weapon systems are discussed in the text, in terms of how they were managed and carried out, to reaffirm the validity of the operating mode described here.

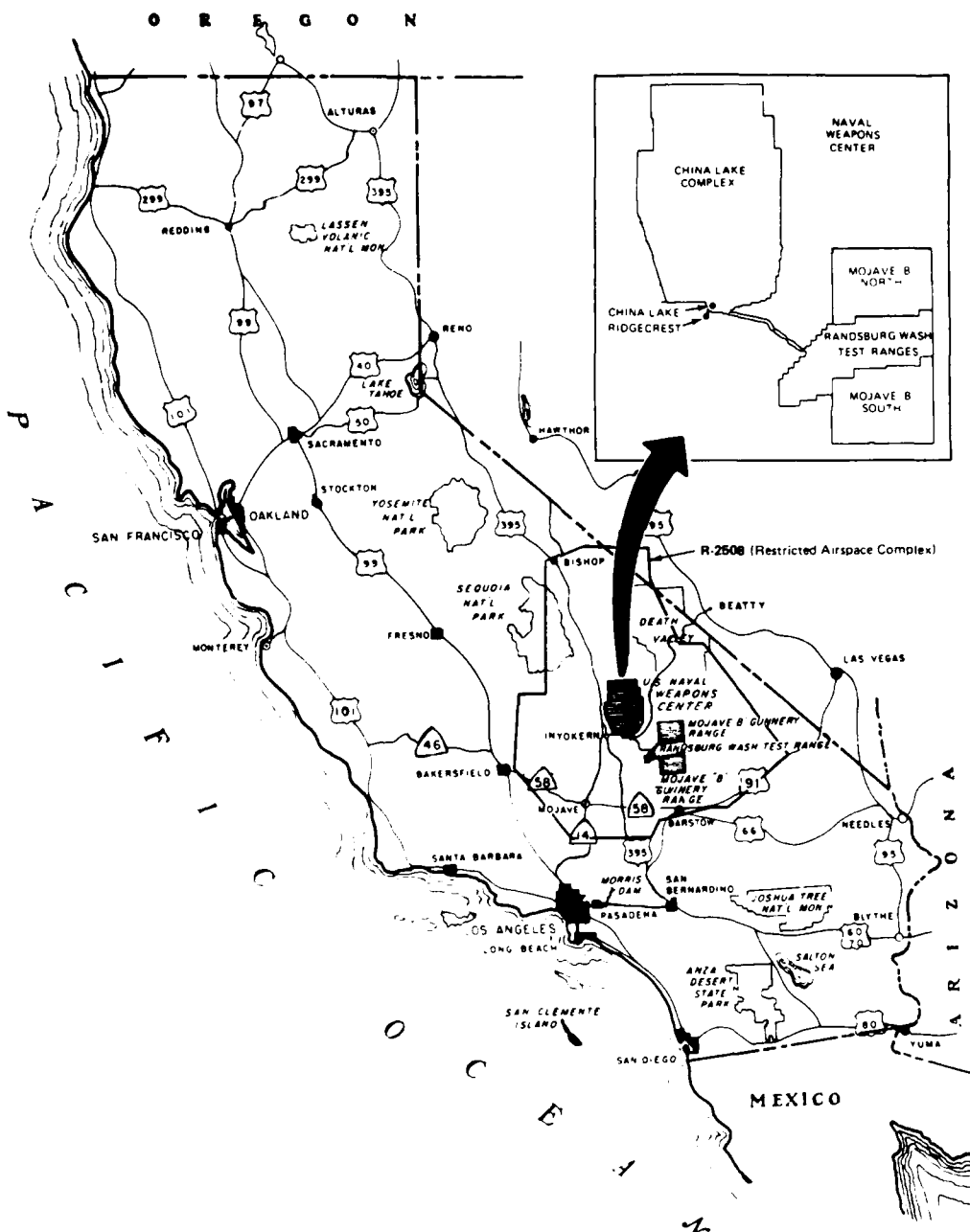
BACKGROUND

China Lake was established during World War II, on 8 November 1943, because the California Institute of Technology (CalTech) needed a bigger proving ground for the rocket weapons that it was developing. The location in the Indian Wells Valley of the Mojave Desert was selected because it was a 3- to 4-hour distance from CalTech at Pasadena, and because an airstrip already existed at Inyokern, about 7 miles from present-day China Lake. (China Lake's Armitage Field was completed in 1945.) China Lake continues to exist today because of the foresight of Navy planners and China Lake leaders in the early postwar period, when the decision was made to retain the wartime test range and create a permanent laboratory and range complex for weapon development. Interest in retaining a remote and secure facility for making the explosives components of the early nuclear weapons (China Lake was already heavily involved in the Manhattan Project by 1945) and doing some nuclear weapons assembly probably helped greatly in supporting that decision.

Because of the remoteness of the location, with no large city closer than 80 miles, it was necessary to build an entire government city of houses, stores, and service establishments, as well as laboratories and other military and scientific facilities—as was done, for example, at Los Alamos. While residential living for the 5,500 civilian employees and 3,000 contractor employees has "normalized" somewhat over the years with the growth of a sizeable city (Ridgecrest) just outside the Center's gates, the area continues to be relatively remote, with the Center dominating the socioeconomic scene. Military presence has continued at a significant level with Air Test and Evaluation Squadron Five (VX-5) and other military tenant activities, as well as NWC's own substantial military staffing for a total of some 1,000 military personnel. Additionally, visiting Fleet squadrons frequently use the Center's extensive test ranges for T&E and training purposes.

The Center today carries a much larger and more diverse work load than it did during its early years as a testing range and as the developer of rocket weapons and the first generation of guided missiles. Presently there is substantial participation in more than 40 major programs, as well as a varied technology base that includes the work of scientists who have gained worldwide recognition, and a test range work load of over 3,000 tests per year that includes a wide variety of test activities limited only by range capacity and the number of people available to do the work. The annual budget now exceeds \$800 million; the Center's \$190 million annual payroll is the foundation of the economy of the Indian Wells Valley region, where close to 40,000 people reside.

NWC does more hands-on hardware work today than it did in the "good old days," acknowledging that software design and computer-aided design is hands-on design even if metal is not actually being bent and shaped. Some of NWC's own senior people sometimes lament that the Center has become bureaucratized over the years, suffering a heavy overhead burden and overloaded with administrators to deal with oppressive regulations—but the facts are that today's overhead burden is proportionately less than it was in the 1950s, if one ignores the "delta" imposed by the relatively recent program for acquiring new equipment, the Asset Capitalization Program (ACP), which came into being in 1983.



Naval Weapons Center and Surrounding Area.

A sizeable fraction of today's overhead cost is associated with the acquisition, depreciation, and maintenance of computer systems. If we could somehow measure the productivity side of the output/cost equation, we would certainly find that the individual engineer is several times more productive than he was years ago, for computer-aided design, computer graphics, the time savings of electronic communication, and the many other benefits of automation have profoundly changed the S&E environment and have multiplied productivity.

HOW CHINA LAKE OPERATES

Military/Civilian Teamwork

An observation often made in advocacy of the in-house laboratories is that military/civilian teamwork is an important factor, and that this teamwork can best be achieved when the civilian element is part of the Government and when military and civilian people are merged in the workplace. It is very important that such interaction be not just among office workers sharing space, but among civilians doing hands-on weapon development work and military personnel with recent operational Fleet experience. With about a thousand military personnel stationed at China Lake, and with operational realities close at hand via extensive Fleet training and test operations, this military/civilian interaction is more evident at the Center than at other laboratories without the strong operational ties. This interaction is essential and contributes heavily to the Center's achievements.

For the most part, the Center has been remarkably successful in maintaining a balance that is equally essential to good dialog, with neither the military nor the civilian element exercising such dominance as to inhibit productive exchange. The Center has benefited from military Commanders whose skill in permitting and supporting the proper atmosphere for scientific creativity and engineering innovation has enhanced the essentially academic atmosphere envisioned by the first Technical Director, L. T. E. Thompson. Ideally, a working partnership exists between the top military and civilian managers of the Center, rather than domination of one by the other.

Diversity of Style

Historically China Lake's managers have not been inclined to conform; the focus has typically been on how to "get the job done" under a myriad of complex regulations that often are not formulated with an R&D environment in mind. This "get it done" attitude has sometimes caused difficulties. Nevertheless, acceptance of diversity and nonconformity is an established part of China Lake's way of doing business and extends to such matters as tolerance of very different management styles and different management priorities within the organization.

Innovation in the Workplace

China Lake's management has historically been willing to pursue new ways of doing business, and to accept the cost of inevitable mistakes that occur when new approaches are tried. The Navy Personnel Demonstration Project initiated by NWC and the Naval Ocean Systems Center is an example. The "Demo Project" offers scientists and engineers distinct personnel management improvements over the conventional civil service system. China Lake had a major role in conceiving and implementing this highly successful management process. The Center contributed heavily to the design and initiation of the Asset Capitalization Program, which for the first time has made substantial funding available for acquisition of modern equipment. In both of these cases,

NWC senior employees were deliberately assigned full time to work on the new concepts and were supported with Center overhead for extended periods. Center managers never said "It is somebody else's business to get these new ideas started"; they took a proactive role.

China Lake foresaw the emergence of the computer age and launched an early (1981) effort to create a Centerwide system of workstations networked to each other and to large computers. NWC was ahead of most not only in breaking away from outdated concepts—old-fashioned mainframes—but also in recognizing the revolutionary impact that minicomputers, microcomputers, and networking were going to have. Although some of the early ideas did not work out, the Center remains ahead of most of the Government in automation because its people and its management got off to an early start and were not afraid to take risks and make mistakes.

Similarly, early recognition of the future role of weapon system simulation resulted in NWC investing heavily in simulation facilities. Again, foresight coupled with willingness to take the risk of being wrong, and willingness to spend resources on promising new ideas, has paid off over the years. NWC was the first to use missile hardware-in-the-loop simulation within the Navy as a major development tool; the Center continues to be a world leader in this methodology.

Quality of Life

The quality of life for employees has always been of great importance to the Center. Over the years Center management has often needed to take on an advocacy role, because the Center's unique makeup and remote location mean that accommodations for its employees have not been typical of a military installation. For much of the time that NWC has existed, most civilian employees resided on the base in government housing, as no alternative was available in this remote region. Even though the adjoining community of Ridgecrest has matured to the extent that civilian housing and amenities are relatively more available, the Center remains the economic base for the whole area. Considering civilian and military employees of the Center and its tenants, including over 3,000 contractor personnel who live here and work solely for the Center, about 10,000 jobs are directly associated with NWC, in an area with a total population on the order of 40,000. Historically the Center virtually was the community and therefore assumed significantly greater responsibility for all aspects of employee work arrangements, recreational activities, and overall security and welfare than would typically be the case for a government activity.

As an example, in 1966 an arbitrary decision was handed down to the effect that civilians could no longer use NWC's commissary or Navy Exchange. At that time there were only two small grocery stores in the community, and it was 90 miles to any supermarket. The Center's thousands of employees were faced with commuting that distance to buy necessities. Center management made an all-out successful effort to arrange for a private-sector supermarket to come in and take over space on-Center to meet employee needs. A few years later, faced with a mandated influx of new people caused by the merger with the Naval Ordnance Laboratory at Corona, and subsequent directed closure of the Corona facility, the Center was faced with the need to house these new people in an area where government housing was full and private housing availability was extremely limited. Again Center management took the lead in resolving the problem and succeeded in obtaining FHIA backing that made possible the emergence of a private housing market in the local area. Similar examples of alertness to employee needs for total quality of life could be mentioned that have occurred over the years.

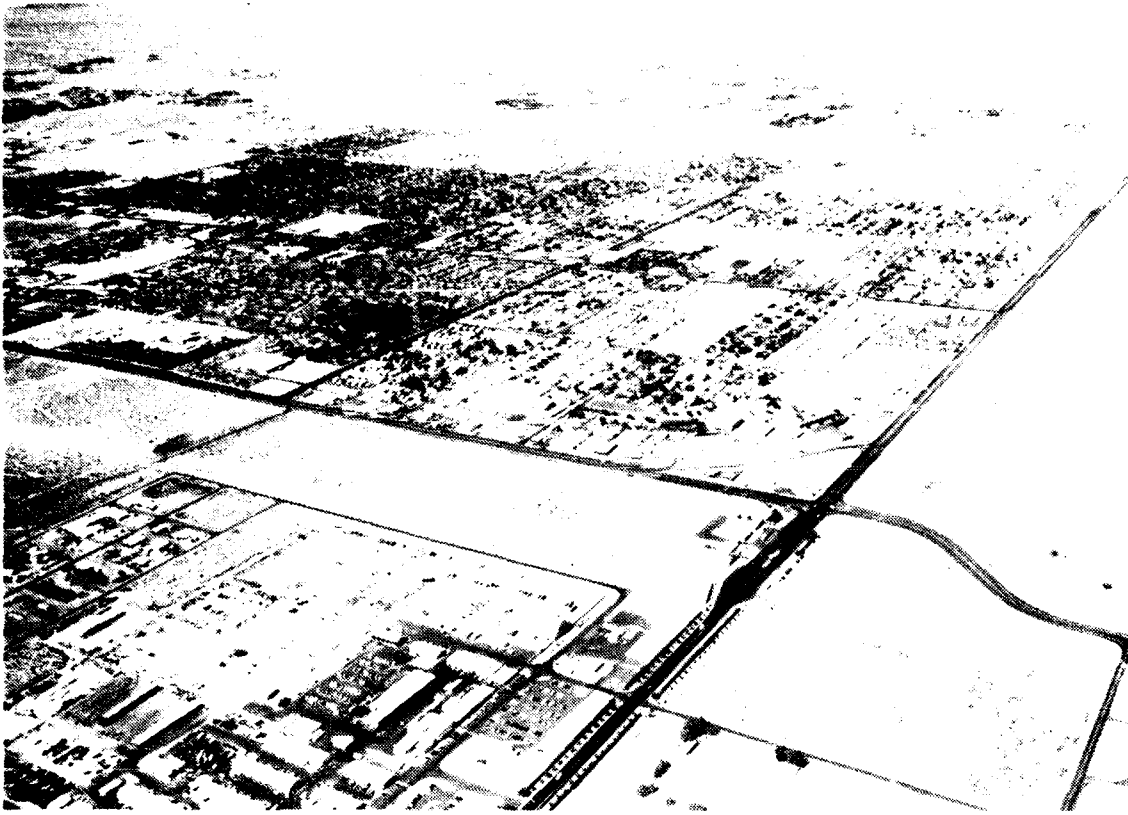


Ridgecrest, 1944.

Environment and Stewardship

With over a million acres of land—desert and, in the north, pinon forests and mountains—NWC has taken on the role of stewardship for a variety of desert and mountain plants and animals, including several endangered species. The ranges encompass petroglyph rock carvings (a designated national landmark) created by Indian cultures centuries ago; there are abandoned gold mines; there are regions of religious significance to Indians of the area where arrangements continue to be made for Indian entry to NWC rangeland for ceremonial and religious activities; there are wild horse herds and bighorn sheep to look after. These things may appear far removed from the development of military hardware, but they are part of China Lake's unique culture, and they play a part in the attraction and retention of the Center's people.

While concern for preservation of the desert environment goes back to the Center's beginnings, potential environmental problems could not be foreseen during those early years. Activities whose work required expenditure of aviation fuel, energetic materials, and toxic chemicals sometimes disposed of these substances in a manner now recognized as harmful to the environment. The Center has, consequently, established a hazardous waste minimization program, involving collective contributions from the safety office, supply and comptroller functions, and the Environmental Project Office (which is charged with overseeing conservation and pollution control issues). Efforts include reduction of on-the-shelf hazardous materials and substitution of nontoxic materials wherever possible, as well as a sustained program to clean up existing hazardous waste sites.

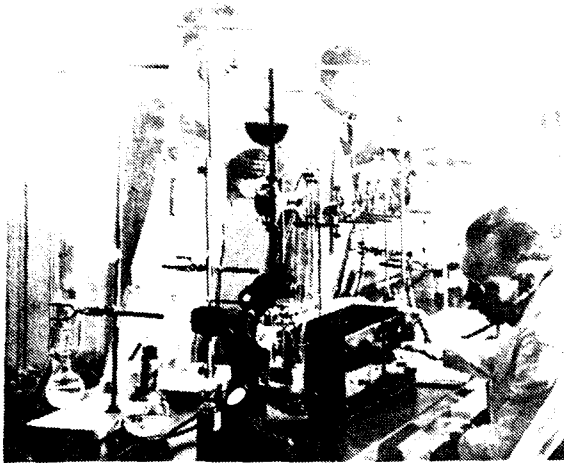


Ridgecrest, 1989.

Technical Leadership

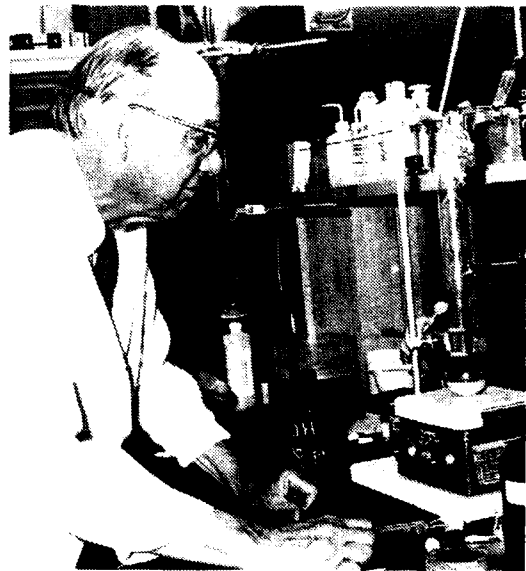
Success in a development program is best attained by putting the program under the control of those who know most about it—the technical experts. Granted, a technical expert is not always an outstanding manager or administrator, but he can be supported with managers and administrators. Senior managers at China Lake almost universally came up through the technical ranks; they are not just MBAs. They know how to manage technical programs and they know how to assess technical merit. The people who best understand the technology that is to be built into a new system should have a key role in its development, whether or not they handle all the personnel actions and buy the supplies.

At China Lake, with its across-the-board capabilities in RDT&E, the same technically skilled individuals can stay with the program through all stages of the development process. This is a key element. It does not mean, of course, that the original innovators or the program managers always stay with the program; a research-oriented innovator may have little desire to stay in the forefront of a full-scale development program, for instance, and a program manager well suited to the development phase may be less well adapted to production support. But the people—hands-on engineers and technicians—involved in the early stages of any given program are generally still at China Lake during later stages and still able to provide technical support and corporate memory as needed.



ROCKET TOWN

Desert community is center for secret research



NWC Chemist Dr. Ron Henry Working in Michelson Laboratory, 1948 (From *Life Magazine*) and 1988.

Evolution of the Center's Role

The Center's successes have been frequently attained in programs where NWC was enabled to continue in a leading role, directly responsible for overall design and program management, with significant participation in the process of full-scale development, test, and evaluation, and complete control of the documentation. A too-early handoff to a prime contractor, with the contractor assuming responsibility for putting the system together and the in-house laboratory relegated to the sidelines as an advisor, too often has been associated with cost escalation and schedule delays. Again, the technical experts need to be in charge and the continuity of their participation needs to be assured.

Years ago weapon systems were much simpler and the in-house laboratory could design and assemble pilot models for testing. Once demonstrated to be workable and successful, the pilot model was ready to go into production. What we now call engineering development was a logical laboratory role. As will be noted in the later discussion of China Lake's products in the Fleet, the

Center's role in the 1940s and 1950s reflected this philosophy. Weapon systems were designed, developed, tested, and even produced at China Lake.

By around 1960 NWC had attained what might be characterized as maturity in understanding of the development and acquisition processes. This maturity permeated the cadre of scientific and engineering managers and meant that the Center recognized itself as part of the responsible element of the Navy that could be relied upon in pursuing a considerable array of diverse programs, and capable of assuming responsibility and accountability for its role. Indeed, what has been called the "China Lake way" is in reality the "NAVAIR way," since Naval Air Systems Command people supported its formalization.

During the 1960s the concept of the laboratory as Deputy Assistant Program Manager (DAPM) for large programs evolved under the sponsorship of the senior management of the Naval Air Systems Command. John Rexroth, a senior NAVAIR executive for many years and known as "Mr. Tactical Weapons," was the principal in evolving the laboratories' role. This was key to the utilization of the laboratories. The Headquarters program manager and "class desks" were in charge, with the laboratory reporting to them as their technical manager (DAPM) and overseeing the industrial support from a technical standpoint. This arrangement replaced earlier fragmentation among various Headquarters entities having separate and diverse charters that enabled them to get involved in a program—sometimes at cross-purposes. Program objectives, timetables, participants, and other elements were defined in a written document, the Technical Development Plan or TDP. China Lake would actually write the TDP, for the SYSCOM program manager. It became, upon approval, the program manager's document—his plan—and could only be changed with his approval. The actual tasking to the Center (called the AIRTASK for programs conducted under sponsorship and direction of NAVAIR) therefore only had to say, in essence, "Execute the TDP." China Lake awarded and managed the contracts associated with the development.

Parallel to the evolution of the DAPM/TDP concepts, contractual arrangements were evolving in the direction of cost-plus-award-fee-type contracts. Center managers were—and continue to be—convinced that with the uncertainties inherent in a new development effort, this form of contract is far superior to a fixed-price approach. The latter may initially look attractive to harassed senior officials trying to cope with cost overruns, but in actuality it only forces contractors to bid so high as to allow for these uncertainties; it costs the Government both money and flexibility in the long run.

What emerged, therefore, as a joint Headquarters/laboratory venture, was the concept of government laboratory in-house design work, followed by government laboratory technical direction to contractors exploiting the design under cost-plus contractual arrangements. The Government controlled configuration management and documentation; Level 3 documentation was required (high precision and intensive detail). As the system moved to production, the Government carried out production plant reviews and, at the appropriate time, entered into arrangements to qualify a second source to encourage efficiency and economy in the production phases of the system's life.

The China Lake role during the 1960s and 1970s, then, was basically to do the critical experiments in-house, build the brassboard models, and create a concept that was appropriate to the military need, capable of performing well, and reasonable in terms of life-cycle cost. At that stage, a request for proposals (RFP) would be issued to start the process of bringing the industrial community into the effort. Proposals could be assessed against the baseline concept that was already in existence. Although some Headquarters people occasionally felt that the Center's objectivity would be affected by bias toward its own design concepts, Center management never felt that this was a reason for concern. The baseline design existed to ensure that the Fleet's needs

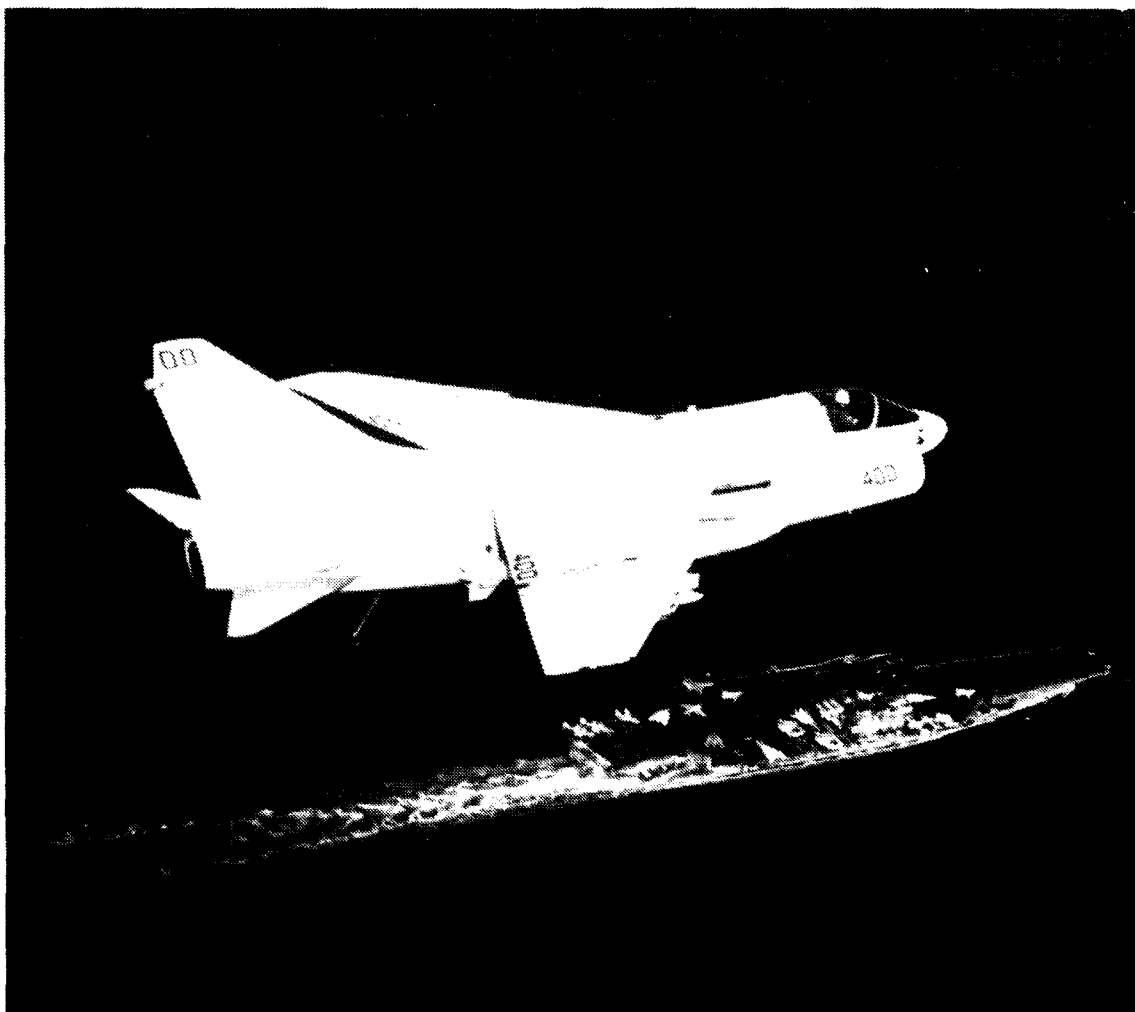


NWC Aircraft Fly-by: QF-86, TA-4, A-7E, QT-38, A-6E, F/A-18, and A-4M Based at Armitage Field.

could be met in an affordable fashion; it enabled Center experts to deal knowledgeably with alternative approaches, and the Center saw its role in evaluating contractor proposals as a vital one for the Navy.

Also during this period, the Center, working with its contractors, built up its understanding of the processes that contributed to high quality production. These processes were continually upgraded and imposed on succeeding contracts through detailed specifications. The resultant quality of weapons delivered to the Fleet was significantly increased. Thus, China Lake entered into one of its most important roles, one that again separated it from other traditional laboratory roles—production support.

Sometimes the Center has gotten into the weapon system improvement and upgrading process through Navy recognition of the need for a good design-disclosure package, which the Center is adept at developing. Sometimes the means of entry is through problems in specific areas where NWC has nationally acknowledged technical expertise—for example, propulsion, seekers, or warheads. There are also myriad programs to which China Lake has made significant contributions, not by doing the original design, but by entering the program after completion of development, to assist in working out problems of production support or product improvements to help make the weapon work better in the Fleet. Confidence thus earned has enabled the Center to get heavily involved in follow-on design and in second-source or leader/follower procurement arrangements.



NWC Planning Supports the Fleet at Several Levels.

Examples include the Sparrow air-to-air missile, the Tomahawk cruise missile, the Harpoon cruise missile, the Rolling Airframe Missile (RAM) for shipboard use in the surface-to-air-role, and the Phoenix air-to-air missile. In most of these very important missile programs, NWC did not do the original design but has assumed a major role in redesign and product improvement. This has permitted entry into new work like the Advanced Cruise Missile and the AIM/RIM-7M and -7P Sparrow (after the AIM-7F Sparrow had failed OPEVAL and the Center's help was called for). Harpoon, too, had major OPEVAL problems. NWC was requested to assist in getting the production under control and solving the reliability problems that plagued OPEVAL. NWC got into Tomahawk because the Center did a good job of assisting in the resolution of Harpoon's reliability problems. The ASN(R&E) dictated NWC's entry into the German-American joint project called RAM when RAM got into serious program difficulties. This whole array of achievements is in a different context than the Sidewinder/Shrike evolutions where original design was at NWC and the Center controlled a series of follow-on programs.

Quality

Recently the concept of Total Quality Management, or TQM, has been receiving much attention in the Navy community. Its principles are those advocated by Dr. Deming and others in the immediate post-World War II era and applied to the restructuring of the Japanese economy after the war—with historic success—and since adopted by numerous private and governmental activities in the U.S. and elsewhere around the world.

China Lake, as a major research and development activity, has always placed heavy emphasis on quality products. It would not be correct to say that the Center has always operated under the principles of TQM; that is not so and still is not so. In particular, it will take considerable time to define and establish quantitative measures that are meaningful in a laboratory environment. However, an important reason why TQM quickly found support at China Lake may be that philosophically, at least, Center managers have long supported its basic elements. Although not specifically called TQM, some of the attributes of TQM were espoused and implemented at China Lake (then NOTS) by Dr. McLean in the late 1940s and early 1950s in his leadership of the Sidewinder program, and later during his long tenure as Technical Director, and the McLean philosophy of management has continued to be valued at China Lake.

To consider the relevance of the China Lake experience to current TQM concepts, let's look at some fundamentals of quality management as expressed in the literature:

1. Satisfy the customer. NWC's ultimate customer is the Fleet, and NWC stays close to the Fleet. Indeed, the Fleet comes to China Lake, to conduct training missions over NWC's ranges—and a thousand military personnel are stationed continuously at the Center. Throughout its history, NWC has sought to understand what the Fleet needs and to utilize this understanding as the foundation for all hardware design. This understanding tries to encompass not only what the Fleet and the sponsoring activities set forth as requirements, but also considers the actual expectations of the customer—basically the expectation that the laboratory can add something useful and valuable to the process, not simply respond to the requirement. NWC also has continuous dialog with the Systems Commands and other sponsors to maintain responsiveness to their needs.

2. Design/build quality into the product. The Center's "products" are reports of research and development conducted and design disclosure packages for items designed and developed here. Backing up these paper products, however, is the extensive hands-on hardware work leading to experimental results or to a new weapon design. China Lake program management practice is to bring the quality-assurance people, the reliability experts, and the people who think about producibility into the design process at the beginning, not near the end. Hands-on hardware work is emphasized for the Center's scientists and engineers, for NWC is convinced that there can be no substitute for this experience if its project people are to keep up with—or ahead of—technology. Nevertheless, the philosophical emphasis on quality has always been present, and the best evidence is the array of accomplishments described in this paper.

NWC's Design Review Committee (DRC), composed of senior scientists, engineers, and managers, reviews all major development programs. The DRC represents a thorough process that has prevailed for many years; it is not an audit; it takes place at key milestones during a development program, and it focuses on maintaining rigorous standards and controls as the development goes forward. Earlier (in the 1960s) the DRC was a detailed technical design review. Today, with more programs and with much more complex systems being developed, the DRC members cannot attain the same degree of technical understanding of the system, and responsibility for integrity of the design basically must rest primarily with the department managers cognizant of the program. As a consequence the DRC has evolved toward more of an overall program management technical review—but it remains a highly important quality assurance process.

3. Set standards of quality and do not deviate. The Center's insistence on quality from its own people is matched by its insistence that contractors meet equivalent standards. We still must regularly relearn the lesson ourselves that "design is documentation" and remind ourselves that the inviolable documentation standards that we demand of contractors must also be demanded of ourselves. (Computer-aided design has helped greatly in recent years, since the documentation results automatically from the design process.)

The emphasis on quality, documentation, and configuration becomes part of the design process throughout, and this emphasis is not allowed to give way to redesign that slights it.

4. Stay with good suppliers. Preoccupation with the lowest bid still dominates the procurement arena. In spite of this, over the years the Center has consistently opted for quality in a contractor's performance, ahead of cost, and has advocated cost-plus-award-fee contracting so that there is concrete incentive to the contractor for excellence of performance. In addition, NWC has tried to establish a team effort with the contractor rather than an adversarial relationship. A cost plus contract is the best contractual vehicle for achieving this end.

5. Recognize that the individual employee is the key. The Center's workplace philosophy assigns value and recognition to the individual person. This philosophy is reinforced by the still-remote small town environment, where people are less likely to recede into anonymity than in the urban scene. It is less likely that the boss will be detached and indifferent toward the employee when the employee is also his neighbor. Project teams and program management offices tend to be small enough so that they really can be "team" approaches to finding the right processes and the right solutions.

6. Be aware that quality can always be improved. An organization must not become complacent and embedded in traditional ways of doing business. NWC has a "tradition" of getting workable products into the Fleet. But the Center's scientists and engineers are not constrained by "traditional" approaches to creating the product. There are always ways of doing it better, and the Center's readiness to innovate—e.g., early entry into microcomputers, networks, simulation, and administrative initiatives like the Personnel Demonstration Project and ACP, as mentioned earlier—reflects its continuing active search for better ways to do things and to improve the quality of its products.

Thirty to forty years ago, China Lake's approach to development involved a lot of live testing: many people on the test ranges, large specialized machine shops, and many technicians to build the breadboard/brassboard models and rebuild them repeatedly until the right design had been attained. In the 1950s, with a total work force nearly the same size as now (about 5,000 civilians), there were actually only 400 to 500 scientists and engineers, compared to the current level of more than 1,900. Today, with design work aided by computer modeling, mathematical models, simulation and graphics, and hardware-in-the-loop simulation, a large fraction of the testing of a design is done in the laboratory. The first breadboard or brassboard model may often be the only one built. The composition of the work force has evolved accordingly—many more S&Es, many more computer and simulation specialists, fewer ordnancemen and technicians. Processes have changed and continue to change. The Center takes great pride in its past achievements but in no way do today's managers advocate a return to past obsolete methods. What we do reiterate is that the philosophies, attitudes, and overall goals that contributed to past successes are just as relevant today as ever.

In summary, NWC endorses the concepts of quality management through quality leadership to evolve constant improvement in our business and technical processes, to meet customer requirements, and to empower a military and civilian team to accomplish tasks across the total Center. The basic principles of TQM are supported by the Center's top management team and have been further supported by middle management and the total work force. A large number of

Center managers and members of the work force have received training in TQM awareness and tools required for TQM implementation.

The Center has a long history of meeting customer requirements with effective products. In past years, as noted earlier, its management team has supported the initiation of the Civilian Personnel Management Demonstration program and other innovative management initiatives that provide the Center's work team with the ability to operate in a creative environment. The origins of the Center's emphasis on technical work teams go back to the early days of participation in development of weapons like Sidewinder, aircraft rockets, Shrike, Walleye, and a family of free-fall weapons, many of which are still in use by U.S. and international military forces.

CENTER FACILITIES

The connotation of a "laboratory" may be something like a red brick building downtown where people do things with test tubes. But the products that NWC deals with have to function in the open sea—and the air above it—on combat platforms and under severe environmental conditions. What works in a test tube may not work in the Libyan Desert or the North Atlantic. The Center's facilities for developing and testing military systems reflect this. The indoor laboratories are complemented with "outdoor laboratories" where real combat conditions can be closely approximated for testing and evaluation. There are 1,100 buildings at China Lake, more than 1,000,000 acres of land, and 20,000 square miles of usable airspace. Thirty-eight percent of the entire Navy's landholdings are represented by China Lake. Replacement cost of existing facilities and equipment would run into the billions; the China Lake land mass is, of course, not replaceable or matchable at any cost.

The following is not meant to offer a comprehensive review of the technical facilities at NWC, but rather a highlighting of some of the significant facilities.

Test Ranges

The first test conducted on a China Lake range (a fuze test of an aircraft rocket) occurred on 3 December 1943, less than a month after the Center officially came into existence. Hand-held cameras and tape measures constituted the instrumentation to record this first firing. Since then the test range complex has evolved to encompass 28 major facilities, numerous special-purpose installations, and some \$500 million in investment (replacement cost would be much higher). The comments below identify a few of the major test facilities and are not intended to provide a complete catalog.

The T&E ranges are operated as an extension of the laboratory. The Range Control Center (RCC) puts an array of range-control functions together under one roof—test control, data recording, communications, airspace surveillance, and drone control, along with real-time processing and data-reduction work. A customer comes in for what is, in effect, "one-stop shopping," with expert advice at hand to tailor test operations to his needs. This enables the customer—the designer or evaluator of the system—to maintain a strong involvement in the testing of the product.

The Center has an array of air ranges; ground ranges; and propulsion, warhead, and environmental test facilities for testing a broad spectrum of weapon systems. The Coso Range, officially called the Military Target Range, constitutes some 70 square miles of mountainous area in the northern part of NWC, with various targets—bridges, tunnels, vehicles, SAM sites—emplaced in a natural forested environment for tactics development and pilot training under realistic conditions.

The Electronic Warfare Threat Environment Simulation (EWTES) facility, also known as "Echo Range," was established in 1966 (operational in 1968). Echo Range accurately simulates the EW environment in a number of land and sea combat situations for testing of weaponry and tactics. The Range was originally developed to address the land-based antiaircraft threat during the Vietnam War. By the 1971-72 time frame, relevant equipment was being obtained and studied preparatory to evolving a suitable depiction of the sea-based antiaircraft threat and by the mid-1970s primary emphasis was shifting to providing the electromagnetic threat environment of surface naval combatants.

Armitage Field is NWC's airfield; covering some 11,000 acres, the Field has three runways and all required aircraft and support facilities to support the NWC RDT&E program. The Field supports aircraft assigned to NWC (generally 30 to 35)—the tenant OPTEVFOR squadron, VX-5, and many transient groups.

Operational since 1953, the Supersonic Naval Ordnance Research Track (SNORT) is a 4.1-mile-long rocket sled track for controlled dynamic tests of ejection seats, weapons, fuze functions, and various other applications. This was the Navy's first extended-length supersonic track.

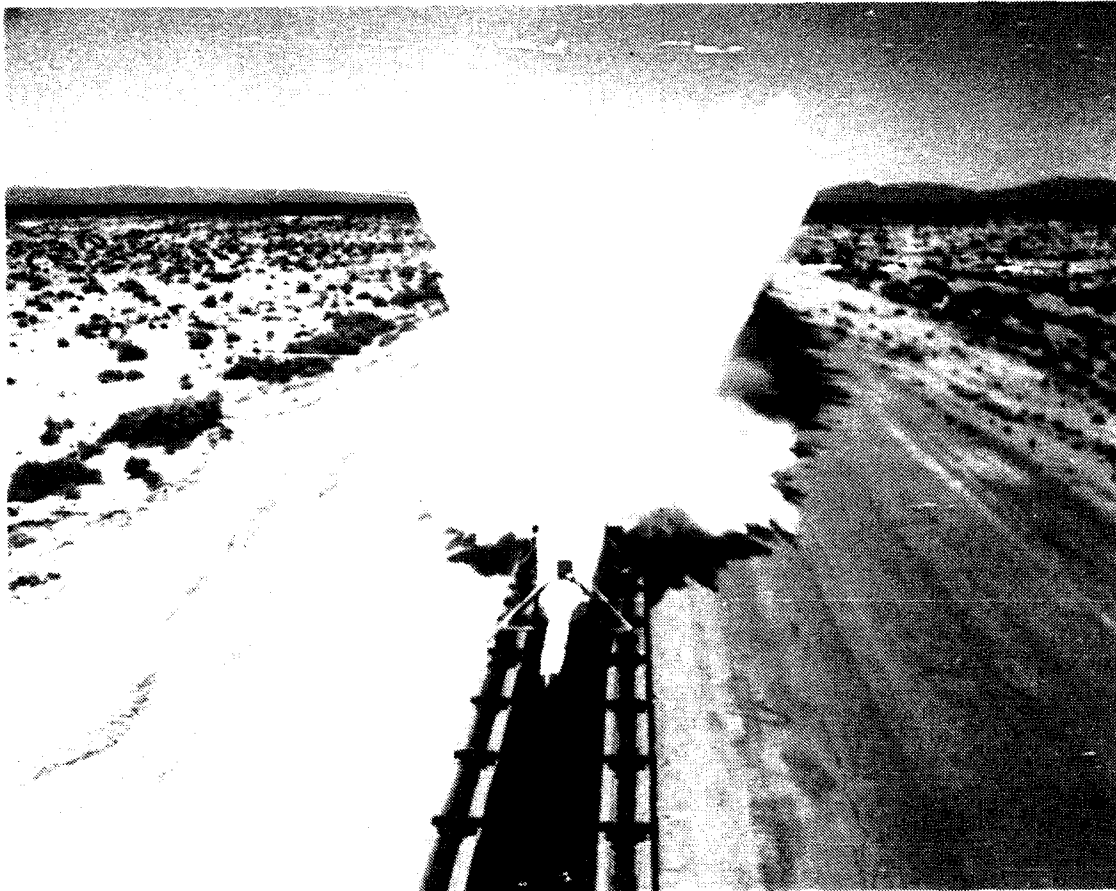
Joshua Ridge is an electro-optics field laboratory—a remote facility in the mountains of the northern ranges for testing electro-optical and laser systems under operational conditions, where propagation paths of several miles are needed.

Junction Ranch is a state-of-the-art radar cross-section measurement facility with two outdoor ranges, including a unique long-range look-down capability, well suited to the kinds of testing requirements that will emerge in parallel with stealth technology.

The Aircraft Survivability Range, completed in 1970, is DOD's only facility capable of conducting tests of the vulnerability of operational aircraft to gunfire or other types of damage, under high-velocity-airflow conditions simulating actual airborne operation. Aircraft systems, engines, and components are tested to determine their ability to withstand various kinds of damage.

Skytop represents the Navy's largest and most completely instrumented complex for rocket-motor testing. Extensive hazardous environmental test facilities exist in this area. The one-of-a-kind Trident Facility provides a suitably remote locale for testing Trident rocket motors. It includes a unique radiographic inspection facility, built into a hillside, which utilizes high-powered X-rays to map and plot the propellant loading of motors prior to firing. The Trident motor test facility is capable of firing motors in positions matching actual flight attitudes—i.e., nozzle positions can be varied from horizontal to vertical.

Minideck is a representation of a carrier flight deck that is the Navy's only capability to test and evaluate carrier and aircraft firefighting systems.



Test in Progress on NWC's SNORT Facility.

Laboratories

Michelson Laboratory remains NWC's principal laboratory complex, with 15 acres of floor space. Its modular design and movable panels, reflective of the initial Bell Labs architecture of the 1940s, have enabled the laboratory to remain viable more than 40 years after it became operational in 1948. It is actually a complex of laboratories that includes the Solid State Facility (radar, laser work, fuze technology, study of electromagnetic phenomena), the Simulation Laboratory (which can simulate actual flight conditions for a missile system and employ the missile itself in a hardware-in-the-loop configuration), a computer wing housing NWC's large scientific computers, an industrial machine shop, and numerous other specialized facilities.

Operational since 1973, Lauritsen Laboratory's 60,000 square feet of space and facilities is largely associated with lasers and optical systems.

Locally called the "Pilot Plant" because pilot-production facilities were created there to manufacture rockets designed at China Lake years ago, the China Lake Propulsion Laboratories are used for development and testing of explosives, pyrotechnics, and propellants. Nearly 400

buildings and structures are devoted to explosive and propellant work. (Originally two "pilot plants" existed—the China Lake Pilot Plant for propellant work and the Salt Wells Pilot Plant, several miles distant, for explosive work associated with nuclear weapons. Today the term "pilot plant" is used for both.

NWC has a long-term commitment to develop and upgrade aircraft weapon systems and tactical software for an array of military aircraft, including the A-6, F-18, AV-8B, A-12 and others. Each aircraft has a Weapon System Support Activity (WSSA), each facility being a computer-intensive hardware-in-the-loop development laboratory designed for system/weapon integration and software development and test.

CENTER PRODUCTS

Products designed and developed at China Lake and released to the Fleet number in the hundreds. The appendix to this report identifies some of these products according to when they were deployed and by functional area. Some of the most significant products are highlighted below.

AIR-TO-AIR WEAPONS

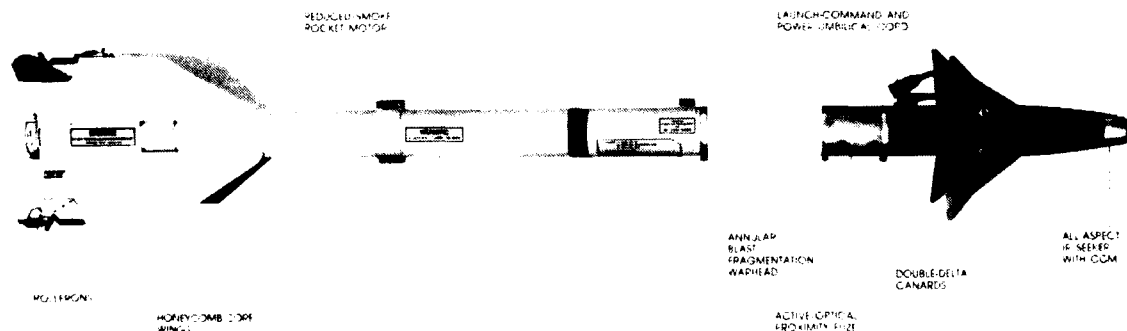
China Lake conceived and developed the first guided missile ever used successfully in air-to-air combat. Chinese Nationalists used the Sidewinder 1A in combat in September 1958, and it has been said that the availability of the Sidewinder may have been a critical factor in heading off an invasion of Taiwan at that time. The original Sidewinder began with exploratory studies at China Lake in 1949 to see if a "sun seeker"—an infrared seeker—could be built. There are stories about the legendary Technical Director, Dr. William B. McLean, building the seeker in his garage. Some say these stories need to be taken with the proverbial grain of salt, given the magnitude of the program and the many talented people who worked on it, but people who are still here remember noting the presence of a seeker in Dr. McLean's garage. The Sidewinder program, eventually completed at a cost of about \$21 million (in 1950s dollars), was conducted in a pre-computer, pre-simulation, pre-solid-state era. At the peak of effort, some 150 target-drone aircraft presentations were taking place per year as evolutions of the design were tested. As an example of the less formal program control in those days, NWC's sponsor (the Bureau of Ordnance) once complained mildly that it had not received an official status report on the program for 2 1/2 years—though telephone contact occurred with great frequency and the sponsor really was fully aware of program status at all times. From the time initial funding was provided, this totally new and different development required 7 years to complete. The original Sidewinder deployed in 1956. (The pilot who fired the first all-up Sidewinder missile was CDR Wally Schirra, then stationed at China Lake and destined later to achieve fame as an astronaut.)

By the time of the Vietnam War, China Lake had evolved the Sidewinder into a solid-state version with a variety of other improvements. It had become "the" air-to-air missile, with most Free World powers using it, and the Soviet Union was employing a stolen literal copy of it as well. The missile accounted for most of the air-to-air kills in the Vietnam War. The AIM-9B version was still in use; this weapon, designed as an anti-bomber system, was not optimal for air-to-air engagements with fighter aircraft. However, the AIM-9D improved version (with a cooled PbS detector and a larger motor) was already operational; as it entered the inventory in large numbers, it proved an excellent weapon. Sidewinder's low cost and high reliability were becoming a legend in the Fleet.

In more recent years, the capability of the missile has been extensively changed. The AIM-9L was a particularly significant development—really a new missile rather than an upgrade, with enormously increased acquisition capability. The AIM-9L has seen combat in the Mediterranean, where it accounted for some Libyan aircraft, and was also effectively employed by the British in the Falkland Islands conflict. The currently developmental AIM-9R, too, is of such advanced design as to constitute to a considerable degree a new seeker system. However, the original torque balance servo concept is still used.

Sparrow is a medium-range semiactive radar homing missile for both air launch and surface launch. It complements the shorter range, IR-homing Sidewinder, and the original Sparrow falls in the same age bracket as the original Sidewinder. Sparrow was not an NWC development; it emerged from a private-sector program during the 1946-1956 time frame. The air-to-air Sparrow missile proved ineffective in Vietnam. When performance problems and reliability problems were encountered, NWC was asked in the early 1970s to enter the program, resolve production and reliability problems, and assist in the development of a second source for production of the missile. The Center was able to expand this assignment not only to introduce a second source, but also to initiate at the same time a variety of design corrections and a much improved documentation package for the system. Although properly characterized as product improvement work, the result was a greatly reworked, high-performance, highly reliable, lower cost Sparrow missile system.

The present-day Sparrow has undergone continuing improvement and is used in both air-to-air and surface-to-air applications. A variant, the NATO Seasparrow, is employed by numerous other countries as a point-defense system for ships. NWC maintains a continuing production support and Fleet support program for the Sparrow missile family.



Sidewinder AIM-9M Showing Components.

AIR-TO-SURFACE WEAPONS

Rockets

The first air-launched rockets ever to enter the U.S. inventory were the result of a World War II joint venture between CalTech and China Lake. The 3.5-inch aircraft rocket (AR) had a 20-pound warhead and a 3.25-inch solid-rocket motor. The 5-inch AR had the same motor. Later there was a new motor and the AR became the 5-inch HVAR or High Velocity Aircraft Rocket, also called Holy Moses. These rockets were extensively used in the Pacific Theater in World War II. The 11.75-inch "Tiny Tim" reached operational use late in the war. At that time China Lake not only hosted a development effort and conducted weapon testing but also produced all-up weapons in great quantities. The China Lake Pilot Plant, which as noted earlier still exists as the principal set of facilities for current propulsion and warhead development work, produced hundreds of thousands of rocket weapons.

After World War II and the decision to make China Lake a permanent laboratory/test range complex, the Center's work continued to be focused on rocket development for several years. The 2.75-Inch Folding-Fin Aircraft Rocket, usually referred to just as the "2.75" and occasionally by its other name, Mighty Mouse, has been utilized in incredible quantities around the world since its development at China Lake in the 1940s. In fact, more 2.75s have been fired than any other item of ordnance other than bullet-type ammunition. China Lake's 5-inch Zuni rocket has similarly been very heavily used over many years. NWC was lead laboratory for the 2.75 and Zuni developments, with technical control of the programs and a direct reporting relationship to the Bureau of Ordnance, which in turn reported directly to SECNAV. (The Zuni, as well as some other early unguided rockets, was originally conceived as an air-to-air weapon, but as the feasibility of creating guided weapons for this purpose became clear, the rocket's role evolved into that of an air-to-ground weapon. (Interestingly, the Zuni shot down a MiG-15 early in the Vietnam War when the MiG let itself get ahead of an A1 Skyraider that was trying to evade it. The Skyraider fired a Zuni and scored a hit.)

The "Eye" Weapons

In the late 1950s the Navy acknowledged a need for a significant upgrading of its conventional (nonnuclear) air weapons inventory. The so-called Connolly studies (after VADM Tom Connolly, one-time Experimental Officer at China Lake) were important in reinforcing this need and in supporting emergence of the family of "Eye" weapons to create a high-level awareness of the need. As the Navy's lead laboratory for air-delivered weapons, NWC had already initiated a number of these programs, known as the "Eye" weapon programs because they were "eye targeted" with an iron bombsight.

One of these was the very well known and heavily used Walleye, a television-guided glide bomb. The Naval Ordnance Laboratory at Corona, which later merged with China Lake to form NWC, had done some exploratory work on a television-guided weapon in the early 1950s, as had others, but technology at the time did not support continued effort. China Lake initiated exploratory studies in about the same time frame. The Center's unique contribution was essentially to make electro-optical guidance practical. Work on Walleye development began in 1959. The glide bomb was deployed in 1967 and was effectively used in the Vietnam War.

Walleye's aerodynamics permit a significant standoff range; aside from the early antiradiation missile (ARM) weapons, Walleye represents the first air-launched guided air-to-surface weapon ever used extensively in combat over a sustained time period. (The World War II Bat saw limited use and accounted for a Japanese destroyer, and the Army Air Force made limited

use of AZON and RAZON guided weapons. Some would say, of course, that the Japanese Kamikaze concept was something like a guided weapon.) Walleye is still in use.

The "Eye" weapons program included development of cluster weapons—canisters containing numerous bomblets that, after aircraft release and splitting of the canister, scatter during free fall to earth, resulting in explosive effects over a considerable area. Rockeye II, which was extensively employed in Southeast Asia (SEA), was conceived as an antitank weapon. Although there were not many tanks in that conflict, the weapon was used and proved to be highly effective against targets such as truck convoys, radar sites, and parked aircraft. A later NWC evolution of Rockeye was named APAM (which stands for antipersonnel/antimaterial cluster weapon). APAM uses the Rockeye canister but has many more, as well as more versatile, bomblets as its payload. A cluster weapon that did not reach deployment (it was cancelled) was called Deneve. However, something much like Deneve came along years afterward; this time it was called Gator, and it is deployed.

The emergent new family of "Eye" weapons also encompassed chemical weapon systems. Notable among these is Weteye. This largely forgotten weapon was stockpiled in quantity and for about 20 years constituted the country's chemical warfare deterrent. It was designed, developed, and produced at China Lake. The intended follow-on was called Bigeye. NWC did not develop the binary (much safer to handle) chemical concept utilized in Bigeye but did exploit that concept in the



Fleet A-6E Snakeye Drop on NWC Range.

development of a complete weapon system. The chemical weapons area is, of course, one of great political sensitivity, and this sensitivity is reflected in the bizarre history of the program. Bigeye was originally started in 1962. It was shelved in 1969, for political reasons, and restarted in 1977, again for political reasons. Development is complete but production continues to be dependent on political or negotiating considerations. Its value may be thought of as that of a bargaining chip in continuing efforts to eliminate all chemical weapons.

Other developments in the "Eye" series included Snakeye, which began in 1960 and entered production in 1964. This system is not a complete weapon system but rather a retarding tail assembly that is fitted to conventional bombs. Very low level bomb delivery was inhibited because of danger to the launch aircraft itself; Snakeye stabilizes and retards the bomb trajectory sufficiently to permit the aircraft to clear the immediate area. Again this has been a high-volume-usage item.

Fuel-Air Explosives

Conventional explosives have limitations with regard to clearing minefields or neutralizing forces protected by bunkers or trenches. Interest in a mechanism that would be effective in such circumstances by exploiting blast or shock-wave effects led to demonstration at China Lake in 1960 of the feasibility of explosively dispersing a liquid fuel in the atmosphere and then igniting it. These early experiments led directly to the Fuel-Air-Explosive (FAE) bomb, with development being initiated in 1962. The initial operational version was deployed to Vietnam in 1970.

The CBU-55A/B for low-speed aircraft and the CBU-72B for high-speed delivery have been in the Fleet since 1972. A current program is the Catapult-Launched Fuel-Air Explosive (CATFAE), which is a surface-launched minefield-clearing device.

Antiradiation Weapons

Shrike

China Lake "wrote the book" on antiradiation weaponry. China Lake's involvement, starting with early paper studies in the 1950s, was actually the Navy's initial involvement. (The Air Force was working on an antiradiation missile (ARM) weapon called Rascal but it was never deployed.) VADM William Moran, who served as Commander at China Lake years later, was instrumental in getting a "small radar penetrator" program under way and funded in 1957. The first two antiradiation missiles were put together from "off-the-shelf" components in 1958. The guidance system was from a missile called Corvus, conceived at the Naval Ordnance Laboratory, Corona, that was cancelled before it became operational. Those first two missiles were filed and hand-fitted together by a small group of China Lake engineers in Michelson Laboratory. The missiles were fired from an old F3D Skyknight aircraft and one of them actually worked and guided to within 100 to 200 feet of the target. That success, the result of a totally in-house effort, generated enthusiasm for funding the Cobra program. Cobra was later renamed Shrike. China Lake, working with Sperry and Texas Instruments, evolved a production version that was released to the Fleet in 1966, although some preproduction models were taken to Vietnam in February 1965. The weapon was conceived back when nuclear war was thought to be likely and manned aircraft were a primary nuclear strike system. Shrike was meant to be a penetration aid—to destroy an enemy radar or force it to shut down as the strike aircraft approached it. In Vietnam the weapon was being used in a tactical war of attrition, and an array of different variants had to be developed expeditiously to cover the enemy radar spectrum. The extraordinary technology advancement that was necessary to meet these operational requirements is long forgotten and probably was not

appreciated even at the time, but it did indeed represent exceptional achievement, particularly in the antenna sections of the many versions. Shrike has been out of production since 1981 but continues to be a highly important element of the operational U.S. ARM weapons arsenal.

HARM

HARM (AGM-88) was conceived by NWC in 1969 as a successor to Shrike. The first missiles were again handbuilt at NWC and first fired in 1973. After that the Center's role in the program was sharply reduced at the direction of higher authority. In its early years, the program never settled down; requirements changed at every major milestone, and there was a diffusion of responsibility. At a DSARC meeting OSD forced the program into an effort to achieve an advanced capability before the program or the technology were ready. (DSARC meant Defense Systems Acquisition Review Committee; now we call it a Milestone meeting.) China Lake's role for a number of years was described by one participant as essentially one of standing by and watching. China Lake did not have anything like the authority that it had had over the Shrike development, and the relatively greater role of others who, regardless of their administrative skills, were not the ultimate experts in ARM technology, was reflected in schedule slip, size and cost growth of the program. HARM finally became operational in 1983. In the later years of HARM's development NWC was able to assume a larger role in helping to stabilize the effort, achieve cost reductions, provide technical consultation, and (more recently) to pursue upgrading of the system. HARM has been in production since 1983 and is a very successful weapon used by both the Navy and Air Force.

Sidearm

Sidearm is an NWC development intended for light aircraft and helicopters that would not be suited for carrying the 800-pound HARM. It is based on the Sidewinder airframe, weighs around 200 pounds, and can be launched from Sidewinder racks. Sidearm utilizes Sidewinder AIM-9C (SARAH—a radar-homing variant of the Sidewinder) guidance and control sections as its modification baseline. It provides a short-range ARM capability.

Other Antisurface/Antiship Weapons

Skipper was conceived at China Lake in 1981 in recognition of a near-term Fleet need for a standoff antiship weapon. The concept was to attach a Shrike rocket motor to a Mk 80 series bomb with a modified Paveway front end to provide a laser-homing capability. The resultant weapon was released to Fleet use 3 years later at a total development cost of about \$11 million. Skipper has seen operational use in the Persian Gulf and elsewhere and proved to be very effective.

NWC has contributed heavily to today's tactical cruise missiles, Harpoon and Tomahawk, although these were not NWC designs. When the Harpoon was initially being conceived in 1968 (it was then called Air-Launched Ship Attack Missile (ALSAM)), China Lake proposed a cruise missile configuration with a turbojet engine. The Navy, which was considering a variant of the Standard Missile for antiship attack, "bought" the NWC concept but gave the design task to someone else. China Lake maintained a supporting role in the development and deployment of Harpoon, and this role became quite substantial as NWC's ability to come into the program and assist in resolving production problems, resolving documentation problems, and introducing design improvements was demonstrated. As noted earlier, Harpoon in its initial configuration failed OPEVAL twice. China Lake played a principal role on a team that went into the prime contractor's plant (as well as to subcontractors), carried out fact-finding activities, put together a get-well program, and worked with the contractor to implement the program. Harpoon has had

remarkable success since that program was implemented. China Lake is now the lead R&D Center for the SLAM development, which can be thought of as a modification and improvement of Harpoon.

Similarly, with respect to Tomahawk, the Center did not design the Navy's long-range cruise missile. China Lake was brought into the program when technical and production problems were encountered. The Center has assumed a major role in production support, in design and documentation control, and in the system upgrading. The importance of these contributions to the Fleet are reflected in the system's current state of readiness.

TARGET-ACQUISITION/FIRE-CONTROL SYSTEMS

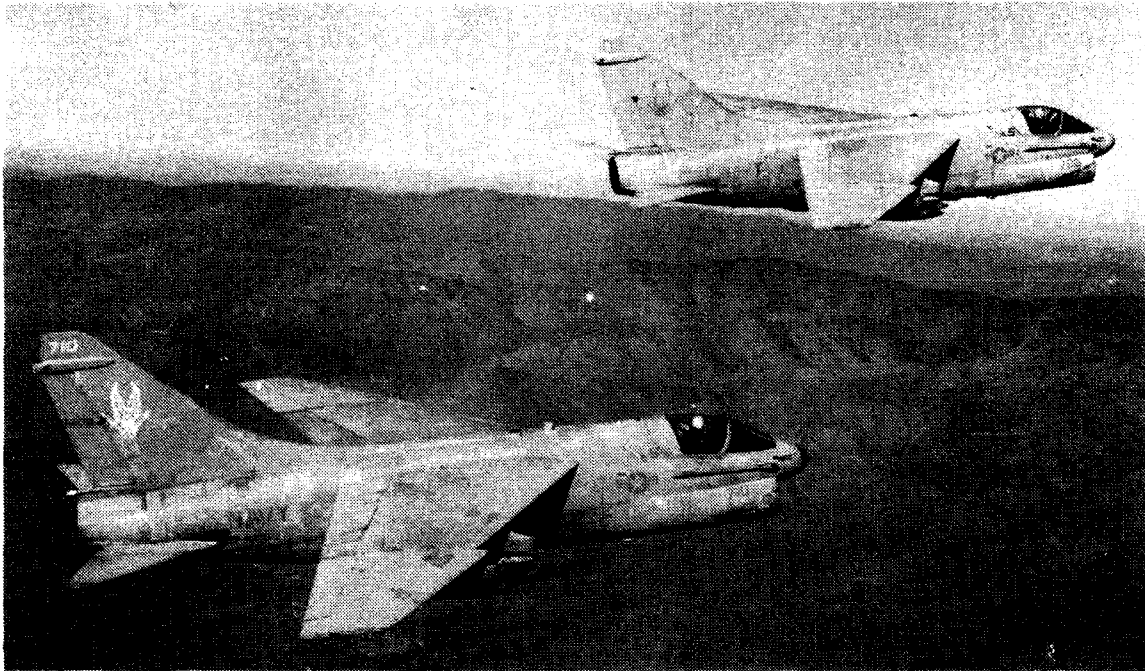
Not long after World War II, China Lake was engaged in developing the Mk 16/EX-16 Armament Fire-Control System for gun and rocket fire control on the F-8 aircraft and the AWA-3 Missile-Envelope Computer for the F-8/Sidewinder and the F-4 aircraft employing Sparrow or Sidewinder weapons. This development led presently to the Sidewinder Acquisition and Track (SWAT) system for the F-8/Sidewinder (1960). The first engineering model of SWAT was designed and flown at China Lake; the follow-on contract (with Magnavox) resulted in an evolution to a contractor design. The Sidewinder Expanded Acquisition Mode (SEAM), deployed in the mid-1960s, was basically a second phase of the SWAT effort.

The original nucleus of weapon-control and -delivery experts at China Lake included a senior scientist who had worked on the Norden bombsight that was carried by B-17s and B-24s in World War II, and the Center's first Technical Director was a principal in the development of that system. Thus the Center's role in the development of heavy-attack weapon-control systems dates back, in a sense, beyond its own time of origin. Continued research on heavy-attack weapon-control systems led to the ASB-7 for the A-3D heavy-attack aircraft and the ASB-8 for the A3J during the 1950s, and in the 1970s to the A6-E TRAM (a day/night attack system for the Navy's current heavy-attack aircraft, with a forward-looking infrared (FLIR) sensor/display and a laser ranging and designating system).

Work on light-attack weapon control systems in the 1950s was associated with an aircraft called the AJB-3—now much better known as the A-4D. The A-4 has had a long career with the Navy and Marines. NWC contributed the CP-741/A weapon-release computer, which became operational in the mid-1960s (also employed on the A-7 aircraft) and the CP-841/A, which became operational in 1969. The Angle Rate Bombing System (ARBS) was originally conceived at NWC, and the Center was lead field activity in overseeing the subsequent development. Operational on the A-4M and AV-8B aircraft, the system was introduced into the Fleet in 1983.

The CP-741/A integration with the A-7E aircraft led directly to the establishment of the Navy's first Weapon System Support Activity (WSSA) for the A-7E at China Lake. Subsequently WSSAs for all the Navy's attack aircraft were created with long-term dedication. The WSSAs have generated an extensive series of Operational Flight Programs (OFPs)—software to accompany the computer hardware and extend or modify the aircraft's ability to exploit its changing family of weapons.

The ADAM (Advanced Development Attack Missile) infrared search set and FLIR display system demonstrated, in 1967, the Navy's first real-time night display of targets for air operations at night. This early development work led to the night-attack systems now operational on naval aircraft.



Two of the Center's A-7Es on a Software Verification Flight.

STRATEGIC WEAPON CONTRIBUTIONS

NWC's name is synonymous with tactical or nonnuclear weapon development, and the Center's considerable contributions to nuclear weapon systems may thus tend to be overlooked. Actually, a number of significant programs existed at NWC, and still exist in the nuclear weapons field. China Lake participated in the original Manhattan Project, notably with regard to casting and machining the high-explosive detonators for the early atomic bombs. (At China Lake this work fell under what was called Project Camel.) This was the original function of the Salt Wells Pilot Plant, which now houses a variety of work in the areas of fuze, warhead, high-explosive, propellant, and propulsion technology. Later the Center carried out Project Elsie, which was associated with the development of a penetration nuclear bomb system. During the 1950s NWC developed the Bombardment Aircraft Rocket, or BOAR. This was an air-launched tactical nuclear weapon, a 30.5-inch rocket—though the blimp-shaped BOAR does not look like a rocket—with a nuclear warhead. It was intended as an interim weapon but ultimately remained in service until 1963.

NWC, working with the Special Projects Office that was then in the Bureau of Ordnance, made major contributions to the definition and initiation of the Polaris Program. Previous thinking had been based on implementing the Army's Jupiter missile system as a surface-ship-based nuclear deterrent. Jupiter was unsuitable for a submarine launch platform due to size, weight, and the liquid propellant employed. NWC's studies under a program called Project Mercury (no relationship to the more popularly known space project) demonstrated the feasibility of a smaller,

solid-propellant missile adaptable to submarine launch. These findings led directly to Polaris, and to subsequent submarine-based strategic deterrence systems. Over the years the Center's T&E facilities have supported a long iteration of test work for Polaris, Poseidon, and Trident propulsion systems.

NOTABLE PRODUCTS IN OTHER AREAS

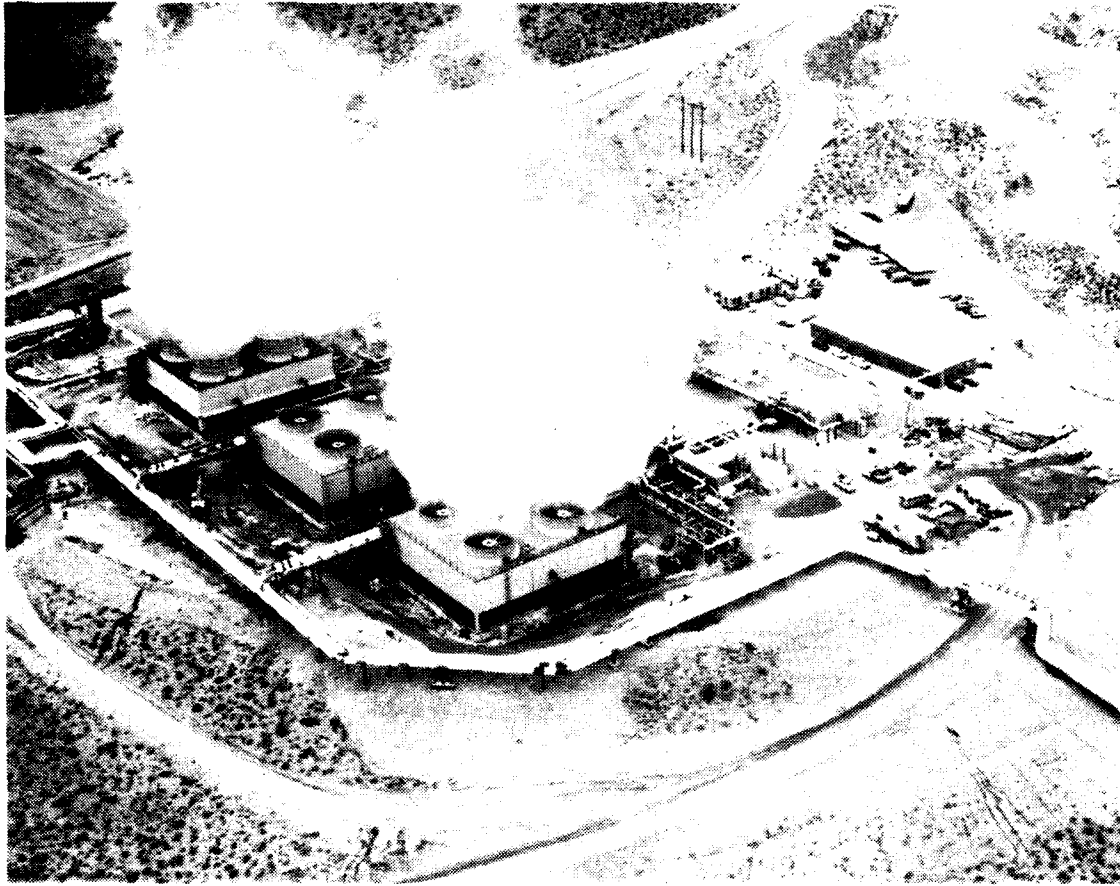
Ship-Launched Weapons. Throughout its history the Navy's primary "air weapons laboratory" has also played a considerable role in the development of ship-launched weapons, often in collaboration with other Navy laboratories. Immense numbers of Spin Stabilized Bombardment Rockets (SSBRs) were employed during World War II for ship-to-shore barrages incident to amphibious operations. These rockets were developed and produced at China Lake. Unguided rocket development declined in the early to mid-1950s as the emphasis on guided weapons emerged, but the Center maintained a capability for many years in SSBRs for shore bombardment, such as were heavily used in the Korean War. Later, in 1963, new concepts permitting a very significant extension of SSBR range and payload led to NWC's development of BOMROC. The Center has long played a major role in supporting the Standard Missile, employed by surface ships for surface-to-air operations, and, as noted earlier, is the principal in-house activity supporting development of the RAM for surface ship applications. Also, as mentioned earlier, NWC serves as technical agent for the ship-launched version of Sparrow.

Moray (TV-1A). Moray was a submersible test vehicle to explore concepts leading to small interceptor submarines. Many new approaches were evaluated, including a free-flooding hull, syntactic foam flotation material, innovative control concepts, and sensor systems.

HITAB. HITAB was a DARPA-sponsored highly instrumented sounding rocket system, to measure IR and UV signatures of ballistic missiles during launch phase. It was part of "Project Defender," a ballistic missile defense program.

NOTSNIK. NOTSNIK was a very early (1950s) attempt at putting a satellite in orbit. The first-stage "booster" was a high-performance aircraft that carried the system to high altitude and launched it. Several launches were attempted, and subsequent to one of these a tracking station in New Zealand picked up "something." While some would doubtless call NOTSNIK a failure, it represented a fascinating story and an extraordinary pushing of then-extant technology to its limits.

Geothermal Energy. An unusual product from China Lake involves the development of a natural geothermal energy site in the north range area of the Center. In 1964 a report was published that predicted the area's geothermal potential. In 1977 a Navy plan was developed for a private industry (third party) contract that would ensure Navy retention of surface management and protection of the NWC mission. The intent was to take advantage of the geothermal energy to generate savings to the Navy for the cost of electricity and to stimulate the Navy's alternate energy program, allowing the Navy to become more independent of foreign fuels. A contract was awarded to California Energy Company, Inc., in December 1979 to produce 75 megawatts at no capital cost to the Federal Government except for local administration costs. The Center received a direct reduction in its electric utility bill for calendar year 1988, the first full year of operation, of \$2.9 million, or a 34 percent reduction in electrical energy cost. When plants 1 and 2 are completed, the Navy will save in excess of \$500 million during the life of the contract. It would take more than 240 million barrels of oil to produce an amount of electricity comparable to that which the Coso Project will produce over its 30-year lifetime. NWC has been assigned the lead role for all Navy geothermal effort, not geographically limited to China Lake.



NWC's Geothermal Energy Site.

RESEARCH AND TECHNOLOGY

The word "first" recurs in this account of China Lake's products—the first aircraft rockets in the U.S. inventory, the first antiradiation missile used in combat, the first air-to-air guided missile used in combat—all developed at China Lake. The technology to pursue tactical missile development itself first emerged at China Lake. A good deal of theoretical work in the early days laid the groundwork for literally all future tactical missile system development. Continued eminence in the design and development of weapon systems rests on a foundation of advanced technology.

Throughout NWC's history emphasis on high quality experimental work has been manifested. The Center has insisted on retaining a substantial Research Department—not a limited-size research staff—because NWC wants to sustain the example of dedication to the highest standards of scientific investigation and to reaffirm the long-term importance of basic research.

ARM Technology

As indicated in the discussion of weapon system developments, NWC has been the Navy's Center of Excellence for antiradiation weapons from the very beginning of the development of these weapons. Since 1965 the advanced technology effort in support of ARM weaponry has been identified with a technology program called ERASE (Electromagnetic Radiating Source Elimination). ERASE has provided the origins of most ARM guidance and target-location capabilities. It has furnished the technology base from which HARM, the HARM Advanced Seeker, and Sidearm emerged. A program that NWC carried out for the Army, the Antiradiation Projectile or ARP contributed key technology to the HARM Advanced Seeker concept.

EW Simulation

An aspect of the Center's technology base that is closely related to ARM weapons development is that of electronic warfare (EW) simulation, along with EW tactics development and training. If Echo Range had not become operational when it did (1968), the U.S. would almost certainly have lost many more pilots in Vietnam than it did. A combination of EW "gadget" development, tactics development, evolution of tactical doctrine, and Fleet training in EW operations, all made possible by Echo Range, was of exceptional importance to the air war in Vietnam. Echo Range and the array of EW technology skills at NWC represent a Center of Excellence for electronic warfare evaluation.

This combination of EW technology and evaluation is not limited geographically to Echo Range itself. NWC has been developing, and continues to develop, training range radar threat emitters for airborne EW training at other locations and for surface ship training ranges as well.

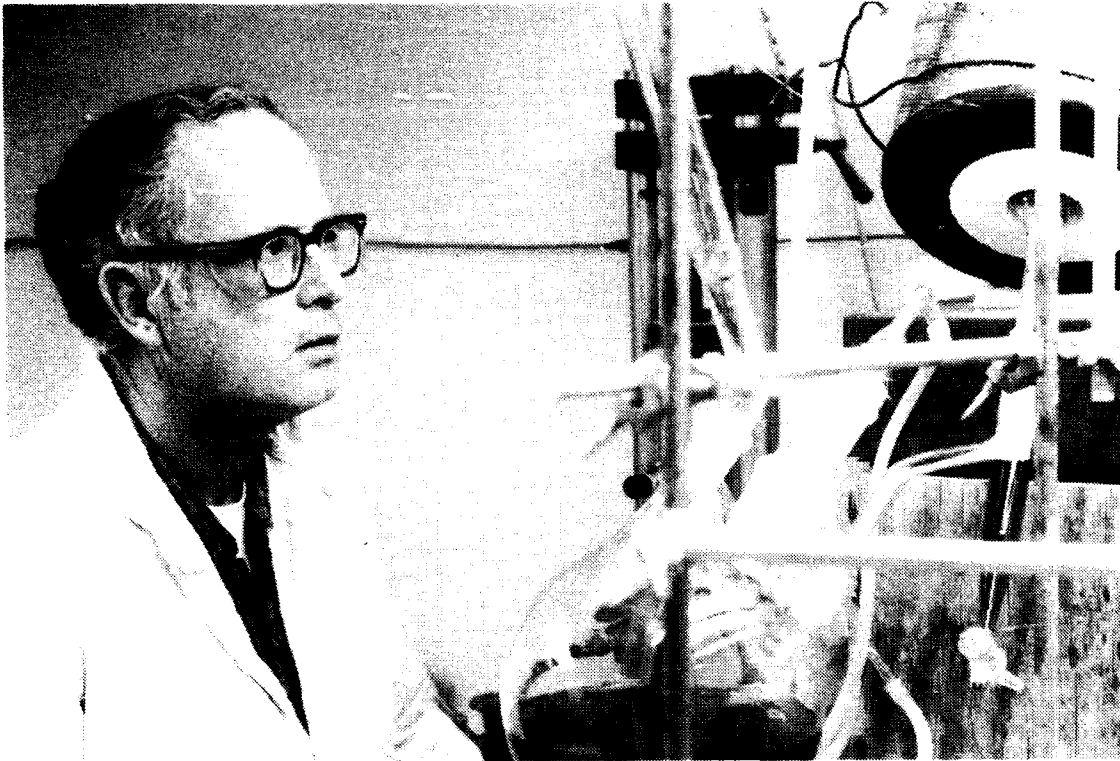
Infrared Technology

NWC has been the Center of Excellence for infrared technology in the Navy since the 1940s, originally for air-to-air applications (Sidewinder). In 1966 NWC initiated efforts leading to the first Navy infrared display of surface targets under nighttime conditions, in a demonstration that incorporated considerable advances in IR technology. As noted elsewhere in this report, the FLIR system evolved from this, as well as the Navy's aircraft night-attack capability.

Explosives

Major research contributions have been made by China Lake scientists in the theory of nonlinear thermodynamics, statistical validation of testing procedures, programs for predicting the results of combustion processes, and other basic research achievements in the fields of explosives and propellants. A considerable part of today's industrial manufacturing procedures for explosives and propellants was originated at China Lake. Major contributions were made in the development of shaped charge warheads. Controlled fragmentation warhead technology originated at China Lake.

NWC was the first Free World activity to synthesize hexanitrobenzene (HNB), which is the most powerful organic explosive known. The first PBX explosives, and most that are now in use, were originally formulated at NWC. These include the explosives used in warheads for Sidewinder, Chaparral, Tartar, Shrike, Standard ARM, HARM, the APAM cluster weapon, Tomahawk, and Phoenix. Various advanced PBX explosives have been developed that are less hazardous than the standard formulations. Recent work in insensitive explosives has been associated with, among others, ADNBF and CL-14, which exhibit performance equivalent to



NWC Chemist Preparing New Chemical Formulation.

PBXN-109, but with very favorable properties relating to insensitivity. The most exciting synthesis is that of CL-20, which offers significant performance increase over common tactical weapon explosives.

Propellants

NWC has developed propellants for Sidewinder, Shrike, HARM, ASROC (antisubmarine rocket), BOMROC, Zuni, and farther back in time for the 2.75-Inch Rocket, BOAR, and many other systems. The Center has an acclaimed capability in the analysis of combustion instability, which has been applied to the Trident and Poseidon programs and to the Space Shuttle booster. NWC is exploring specially tailored liquid and solid fuels for ramjets, offering higher energy and range increases on the order of 25 percent.

Fuze Technology

The Naval Ordnance Laboratory (NOL), Corona, was for many years the Navy's principal in-house laboratory for guided missile fuze development. NOL merged with China Lake in 1967 to form the Naval Weapons Center. By 1971 the Corona facility was largely closed down and the fuze programs had relocated at China Lake.

NWC developed the first active-optical fuzes using solid-state lasers—the DSU-10 for the Standard ARM (developed in 90 days during 1968 to meet a Vietnam War requirement), the DSU-15 for Sidewinder, and the DSU-19 for HARM. The active-optical fuze provides a proximity sensor that is immune to electronic countermeasures.

Short-pulse radar fuzes have been developed for all-weather functioning, using the NWC-developed fore and aft technique for better burst control. These are used on the AIM-54A Phoenix, Tartar, Terrier, and the Standard Missile. This technology has been exploited in over 30 years of Fleet use. The Center has exploited pseudonoise modulation for CW radar fuzes for the Phoenix AIM-54C and the Sparrow AIM/RIM-7.

The Center developed the China Lake Universal Rocket Motor Arming-Firing Device (AFD) to prevent tragic accidents such as the 1967 disaster aboard the U.S.S. *Forrestal*. The Universal AFD has been applied to many missiles including Seasparrow, Harpoon, Tomahawk, Standard Missile, and RAM (currently under development). This single device replaces a vast proliferation of rocket motor AFDs that were in the Fleet until the 1970s, and offers significant improvements in safety and reliability.

Aerodynamics and Thrust Vector Control

Thrust Vector Control (TVC) technology for tactical weapons developed at NWC 20 years ago is now enjoying a wave of applications for the new family of vertically launched shipboard missiles: Tomahawk, Standard Missile, and the Vertical-Launch ASROC. The early work was given considerable impetus by the AGILE program—an air-to-air missile that had movable-nozzle TVC. The program was terminated in 1974. TVC studies continued, however, in recognition of an ultimate need. In 1981 Center engineers successfully demonstrated a combination of jet vane TVC and movable-nozzle TVC, and in 1982 an integrated aerodynamic-control-surface, movable-nozzle TVC (AERO/TVC) system was demonstrated. A powdered metal sintering project for jet-vane manufacture was completed and implemented in 1982. As unmanned air vehicles become primary combat platforms, with maneuverability not restricted by human limits, the high maneuverability of TVC systems will become essential for counterweapons.

Optics

The Center is internationally known for its work in optics associated with laser mirrors. Significant work in diamond turning of precision optics moved forward in the 1980s. The Center's continued support of optics research for high power lasers has contributed to research for the Strategic Defense Initiative. Extensive contributions to radome design and the use of advanced materials capable of functioning in a hypersonic, high-erosion environment are noted. A recent achievement was the synthesis of diamond coatings from methane gas, yielding promise eventually of free-standing diamond radomes.



Optics Research at NWC.

Soldering Technology

Soldering technology rose out of an environment at the Center that included testing and evaluation of contractor-developed hardware. The need for excellence in soldering of increasingly complicated weapons grew as the focus shifted from developing new systems to increasing the reliability and performance of existing designs. Formal soldering technology activity began in 1966. The military specification (WS-6536) that evolved from this was subsequently applied throughout the Department of Defense. It has been said that this specification was responsible for saving DOD countless millions of dollars by forcing discipline into soldering programs. It was because of that specification that the Soldering Technology School was established in 1977 to train contractor and government personnel in the requirements of weapon specifications and techniques. With the advent of MIL-STD-2000, the school was in the forefront, developing the curriculum used throughout the Defense Department for training and certification meeting the requirements of the new standard. The school has been expanded under contract operation and currently trains hundreds of personnel, offering an 80-hour initial certification course, as well as a 24-hour MIL-STD-2000 conversion course for those who have previously been certified and who meet other eligibility requirements. The training stresses "hands on" approaches to the soldering process (both hand and machine), solderability testing, cleanliness testing, electrostatic discharge control, inspection and defect detection, and process controls that lower defect rates and increase production.

Technology Transfer

NWC has been a leader among federal laboratories in stimulating the application of defense and space R&D products to civilian problems and in catalyzing the formation of the Federal Laboratory Consortium for Technology Transfer. By 1970 a basis had been established for a technology transfer program at China Lake that provided technology transfer initiatives in four areas: (1) telecommunications on radar systems, video frequency data conversion, data displays, test facilities, and a design for an airport firefighting system for short takeoff and landing airports for the Federal Aviation Administration; (2) low-light-level television, voice scramblers, patrol car tracking, and personnel communication links for the Law Enforcement Assistance Administration; (3) biomedical ideas for the National Institute of Health; and (4) an air quality control monitoring program to conduct mapping of aerosols for the State of California. Other contributions resulted from investigations into wind, solar, and geothermal energy; solid waste conversion to clean burning fuel; and aircraft survivability. An explosive device was developed to clear fire lines for the Forest Service.

From this effort developed a consortium of DOD laboratories in 1971, devoted to technology transfer and technology utilization. With NWC leadership and assistance, the Federal Laboratory Consortium was institutionalized in 1974 with the support of the National Science Foundation, which included 70 federal laboratories from all major R&D-intensive federal agencies. Subsequent years have witnessed a burgeoning of technology transfer activities in the remainder of the Federal Government. The Stevenson Wylder Act, PL 96-480, of 1980 now requires federal agencies with an R&D effort to have offices of research and technology application to spearhead the transfer of promising scientific and technical ideas to the non-federal sector.

Salient Technical Achievements

Following are a few examples of NWC's technical achievements of unusual significance that did not specifically emerge in the preceding generalized discussion of technology areas:

NWC developed techniques for explosive bonding of metals, which subsequently resulted in the widely used industrial technique of explosive welding. (These techniques are known in the USSR as "Pearson Welding" after the NWC scientist who was the principal in their development.)

TIGS/ATIGS (Advanced Tactical Inertial Guidance) represented an early guidance application of the ring-laser gyro.

NWC contributed significantly to the development of chemiluminescent devices (cold light created by chemical reaction), which now have important commercial applications.

An NWC-developed Automatic Ship Classification System (ASCS) was demonstrated in 1982.

The EGGNOG system—lightweight, broadband radar jamming capability for Marine Corps ground forces—was successfully demonstrated in 1982.

The Fighter/Attack Avionics Technology Demonstration (F/AATD), completed in 1987, demonstrated multisensor correlation tracking for the F/A-18 aircraft in the air-to-air mode. This demonstration provided the basis for implementation of multisensor tracker algorithms in an operational U.S. Navy tactical aircraft.

The first computer that literally works like an organic neural network was demonstrated in 1989.

Major contributions to the technology of fiber-optics guidance for air-launched weapons were demonstrated in 1989.

A new process for producing high-quality, high-resistivity thin films of aluminum oxide on electronic material surfaces was discovered by NWC scientists. This discovery may allow the implementation of high-speed gallium arsenide electronic devices in numerous military applications.

QUICK-RESPONSE ACHIEVEMENTS

The ability to respond quickly to an emergency need requires continuous close interaction with the Fleet and "corporate memory" that knows what will work and what has been tried. Perhaps the fact that NWC was created in a wartime environment and chartered to work time-critical problems made a lasting impression on the Center's way of operation.

NWC's record of quick-response accomplishments goes back to World War II. Collaborative efforts with CalTech made possible the design, development, testing, and production of Holy Moses 5-inch rocket weapons within a matter of months; Holy Moses was operating in combat by August 1944.

During the Korean War an urgent need arose, just after the North Korean invasion, for something that could stop the North Korean tanks, which had what was alleged to be 13-inch armor. That was not true; a tank with that weight of armor probably could not have moved. But the armor was 5 inches thick and the need was real. Within 29 days NWC developed a shaped-charge warhead to match with the 5-inch HVAR motor and produced quantities of the resultant weapon, and the weapon was in service in Korea. This Antitank Aircraft Rocket (ATAR) was also called Ram. For a time during that urgent process the whole main hall of Michelson Laboratory was turned into a fuze production shop with clerks as well as engineers working on the "production line."

In 1962 the Cuban Missile Crisis—with Soviet medium-range nuclear missiles set up in Cuba—was complicated by the arrays of radar defending the missile sites. The U.S. had no antiradiation missile, but Shrike was under development at NWC. An urgent message was received to provide Shrike missiles at once, even though the system was not yet at the end of development. Two hundred missiles were built, about half produced at China Lake and the others at Texas Instruments, with NWC and Texas Instruments working in concert. Alternate guidance sections had to be designed "from scratch" on an urgent basis. Even though most of the hardware was built by engineers and technicians in some small rooms on the floor of China Lake's Hangar One, system reliability was phenomenal. After the missiles had been deployed for a number of years at Cherry Point, some were sent back and fired in training exercises, and every one worked properly. Numerous examples of quick response occurred during the Vietnam War. Some of the early involvements arose out of programs called VLAP and Special Projects.

VLAP (Vietnam Laboratory Assistance Program) was initiated in 1966 to provide scientific/technical advisors to the Fleet and the Marines in the Vietnam War. Tasks were of a quick-response nature—quick fixes, typically inexpensive, to emergent problems. NWC was West-Coast program coordinator of the program until 1970; throughout the conflict the Center provided on-scene support, backed by design effort at China Lake. VLAP ended in 1972 but served as a model for the still-ongoing NSAP (Navy Science Assistance Program).

Many individual contributions were made during the Vietnam conflict (some 50 specific and identifiable tasks were addressed by NWC personnel). Included were a small ground beacon for use by ground troops in identifying themselves to A-6 attack aircraft (1968); map illuminators (1969); hand-emplaced FAE canisters for mine clearance (1970); an interim lightweight gun pod for the Marines (1970); and many others.

The Special Warfare Program, also called "Swimmer," carried out quick-response efforts in support of underwater demolition teams operating in SEA from 1965 to 1972. A large array of specialized devices was developed. Various swimmer-emplaced mine developments led to the LAM (Limpet Assembly, Modular) in 1970, later the UEU (Underwater Explosive Unit), and the Mk 5 Mod 0 LAM, which emerged in 1981. The Swimmer Program developed a Swimmer Delivery Vehicle (SDV) during the 1970s; an advanced SDV had been released to limited production at the time cognizance over the program was transferred to Naval Coastal Systems Center (NCSC). The Actuation Mine Simulator (AMS) on which work commenced in 1965 was a highly successful device for training in minesweeping.

Late in the war the North Vietnamese were able to import a new antiaircraft missile system that was highly effective. An urgent need to find ways of countering the system was expressed in the form of a phone call from the Marine Commander in Vietnam to the Associate Technical Director at NWC. NWC carried out field tests of available equipment and feasible tactics the same day the call was received and provided recommendations via message traffic that night. That effort, plus the rapid development and deployment of a new decoy device, is believed to have saved numerous aircrews and aircraft.

Pave Knife was an Air Force laser target designator (a pod). NWC got involved in a quick-reaction program during the Vietnam War to adapt the designator to the Navy's A-6 aircraft. The designator was used as an interim system pending completion of NWC's A-6E TRAM system. This was an extremely successful venture, completed on time and deployed expeditiously.

Shrike on Board (SOB) was another quick-response effort to adapt the Shrike to shipboard launch, for purposes of destroying or deterring North Vietnamese coast-defense radars. The SOB system was used effectively in combat, 104 days after the initiation of the program.

The Night Observation Gunship (NOGS) was a 1-year program to provide the Marines with a night capability for supporting ground forces. The program involved modifying an OV-10A aircraft to include a FLIR sensor and a 20-mm gun. The system was successfully demonstrated in combat in 1971. Later it became the OV-10D version of the OV-10 aircraft, which went into production in 1978.

CONCLUDING COMMENTS

The Navy is an interesting contrast between tradition and change. The military rituals, the nostalgia surrounding the Academy, and the spirit of the ancient warship in Boston Harbor, all contrast with the constantly changing technology that underlies our modern weapon systems. The Navy's management (ironically mandated by tradition) is also in a constant state of change. Appointed civilian officials come and go with a half-life on the order of 18 months. Senior military officers, both the program managers in Washington and the officers at NWC itself, are rotated every 2 or 3 years, and then they are gone.

This system has advantages, of course. It promotes the entry of new ideas and approaches and helps prevent an organization from becoming isolated and embedded in its own parochial ways

of doing things. It has drawbacks too; it robs an organization of corporate memory at the highest management levels. Sometimes there is little apparent awareness at Headquarters of events that occurred at the Center more than a couple of years ago. Occasionally an incoming military manager or civilian appointee can fail to recognize the traditions and the proven effectiveness of a place like China Lake and can inflict severe damage before realizing the full impact of his action.

H. G. Wilson, former Technical Director at China Lake, commented on the "fragility" of the China Lake environment and way of operating in urging his successors to recognize and conserve the uniqueness of the Center. CAPT J. J. Lahr, former Commander, said something similar when he described China Lake as a "national treasure" that must be preserved. This document has summarized some of the basic and persisting aspects of the Naval Weapons Center, and a few of the accomplishments of China Lake over the years, in the hope that it may serve to refresh and communicate the message conveyed in earlier years by Center leaders to today's audience of military and civilian managers in the Navy.

Appendix

CHINA LAKE PRODUCTS IN THE FLEET 1944-1989

AIR-TO-AIR WEAPONS

Sidewinder AIM-9B. IR homing missile. (Initial AIM-9A version was developed in 1956, but quickly gave way to much-improved AIM-9B.) AIM-9B retired from service in 1975. NWC designed. Tube electronics, no rollerons, small solid-rocket motor, uncooled PbS detector.

Sidewinder AIM-9C. Semiactive radar homing version of Sidewinder. IOC was 1964. NWC designed.

Sidewinder AIM-9D. Improved IR-homing Sidewinder, IOC 1964. Cooled PbS detector, larger motor.

Sidewinder AIM-9E, 9J. Air Force versions of Sidewinder during 1960s and 70s.

Sidewinder AIM-9G. Evolution of the AIM-9D. IOC was 1968.

Sidewinder AIM-9H. Solid-state version of the AIM-9G, increased maneuverability, entered service in 1973.

Sidewinder AIM-9L. Major change in Sidewinder, more revolution than evolution. All-aspect acquisition capability, increased maneuverability. NWC was lead field activity and technical manager.

DSU-15A/B. Active-optical TDD for AIM-9L and AIM-9M. Released for service use in 1979.

Sidewinder AIM-9M. Upgrade of AIM-9L. Released to Fleet in 1981.

Reduced-Smoke Rocket Motor. For AIM-9M. Released to production in 1982.

Sparrow AIM-7F. Not an NWC design. NWC was brought in to deal with performance and reliability problems and to qualify a second source for procurement. Numerous improvements were made to the system in the course of creating a proper design disclosure package. NWC was lead laboratory, DAPM for second source.

AIR-TO-SURFACE WEAPONS

Holy Moses (5-Inch HVAR). Originally a CalTech/NOTS development during World War II. Improved versions were developed by NOTS subsequent to the war. Many of these 5-inch rocket motors were used for years afterward.

Tiny Tim. An 11.75-inch aircraft rocket developed by CalTech/NOTS during World War II and modified for better performance by NOTS after the war.

RAM (6.5-Inch ATAR). Antitank aircraft rocket, developed in very short time for an urgent requirement during the Korean War. In service from 1950 to 1953. NWC was lead laboratory.

Mighty Mouse (2.75-Inch FFAR). Aircraft rocket, deployed 1952, still in use around the world. Many millions of these rockets have been produced. NWC was developer and lead laboratory.

ZUNI (5-Inch FFAR). Folding-fin aircraft rocket designed, developed, and initially produced at NOTS. IOC 1956. Used all over the world; prodigious production figures.

BOAR (Bombardment Aircraft Rocket). Standoff weapon with nuclear warhead, developed by NWC as interim weapon but deployed from 1956 to 1963.

Fireye. A fire bomb for which NWC had DAPM responsibilities in the 1960s.

General-Purpose Projectile, 20 mm. NWC had DAPM responsibilities for development of an improved 20-mm projectile during the 1960s.

Gladeye. A modular weapon dispenser, designed at NWC and completed in 1963.

Weteye. A chemical bomb conceived and developed at NOTS in the 1960s. The bomb finished OPEVAL and went into initial production in 1965. Not deployed because of political decisions relating to chemical weapons, but was considered available to the Fleet should those decisions be modified.

Sadeye. Cluster bomb dispenser, stockpiled from 1964 to 1970. NWC was lead laboratory.

Snakeye. Retarding tail assemblies for general-purpose bombs, IOC 1964. NWC developed and was lead laboratory.

Shrike (AGM-45). First ARM weapon, deployed 1965; some versions are still in inventory. NWC developed and was lead laboratory. Shrike Mods 3B and 4 IOC was 1968; 7 in 1969; 6 in 1970; 8 and 9 in 1974.

Walleye 1. TV-homing glide bomb, deployed in 1967, heavily used in Vietnam. NWC designed. NWC role was lead technical activity.

Standard ARM (AGM-78). ARM weapon based on Standard Missile, contractor-developed under NWC technical direction. IOC 1968; modified version, the AGM-78C, had IOC in 1970, -78D in 1973, -78D-2 in 1974. NWC had lead laboratory role.

Rockeye II. Cluster bomb, IOC 1968. Heavily used in SEA. NWC was lead laboratory.

FOCUS I (AGM-87A-1). Air-to-surface variant of the AIM-9B, for night attack against IR-emitting targets. Saw limited but effective use in Vietnam in 1969-70. NWC was lead laboratory.

Helicopter Trap Weapon. For clearing helo landing zones. Deployed 1969. NWC was lead laboratory.

Lightweight Gun Pod. Quick-response development during Vietnam War. Pod for the OV-10 aircraft to carry the Mk 12 20-mm gun. NWC was lead laboratory. Interim system, in service from 1969 to 1971.

FAE (Fuel-Air Explosive) (CBU-55/B and CBU-72/B). Free-fall weapons providing blast effect against varied ground targets, based on NWC technology and with NWC as principal field activity during development. IOC 1970 for CBU-55/B, 1973 for CBU-72B; still in inventory.

Walleye II. Larger warhead than Walleye I, IOC in 1973 with considerable use in Vietnam. Again, an NWC design with the Center designated as lead technical activity.

Extended-Range Walleye. Incorporates data link and other changes to extend Walleye standoff range. NWC designed and was lead technical activity. IOC was 1974 for Extended-Range Walleye II; 1983 for Extended-Range Walleye I.

APAM (Antipersonnel/Antimaterial Cluster Weapon CBU-59). Rockeye dispenser with a more formidable payload—different bomblet. NWC was lead field activity. IOC in 1974.

Condor (AGM-53A). A long-range TV-guided missile. Successfully completed development and evaluation in 1974. Condor was not deployed although a number of weapons have been stockpiled. NWC was lead field activity and technical manager.

GPU-2/A 20-mm Lightweight Gun Pod. For various strike aircraft and helicopters. Released for limited production in 1974. NWC was lead laboratory.

Gator (CBU-78/79). Air-delivered antivehicle and antipersonnel land mines. Triservice program; NWC was technical representative for the Navy and Marine Corps. Released to production in 1982.

Skipper (AGM-123A). Combination of Shrike motor, conventional bomb, Paveway front end; developed in early 1980s; Skipper 2 version IOC 1983; saw considerable use in Mediterranean/Gulf.

Harpoon (AGM-84A). Turbojet-powered antiship cruise missile, not an NWC design. However, the Center was designated lead field activity for the ordnance package development and provided substantial technical support in other areas.

HARM (AGM-88A). Intended as replacement for Shrike and Standard ARM. Originally called Shrike 73. NWC was initially lead laboratory and technical manager and designed and fired the first three missiles before contracting with industry; after several years as a "bystander," the Center was brought back into a stronger role in the program. First production deliveries in 1983.

Laser Maverick (AGM-65E). Approved for limited production in 1983. NWC was not the designer of the Maverick but became heavily involved in modifications and refinements to the system, providing technical assistance to the Air Force.

FMU-139/B Electronic Bomb Fuze. Approved for limited production in 1983.

HARM Secure Telemetry Section. Designed and produced at NWC for HARM test vehicle launches, completed in 1986.

Mk 83 GP Bomb Fill. Loaded with new explosive PBXN-109, released to limited production in 1986.

FMU-140/B Bomb Fuze. Approved for limited production in 1986.

Sidarm (AGM-122A). Short-range antiradiation weapon for helicopters and light aircraft. Approved for limited production in 1986.

Bigeye (BLU-801B). A binary chemical weapon, originally under development in the 1960s. After various starts and stops dictated by political issues rather than technical ones, the system was eventually completed but not deployed. NWC was DAPM in the 1960s.

Air-Inflatable Retarder (BSU-85/B). High or low drag capability for delivery of the 1,000-pound Mk 83 bomb. Approved for limited production in 1987.

TARGET-ACQUISITION/FIRE-CONTROL SYSTEMS

AFCS Mk 16/EX 16. Armament fire-control systems developed for various strike aircraft (analog computer systems) during 1950s and 1960s. NWC was lead laboratory.

AWA-3 Missile Envelope. Computer for F8/Sidewinder, F4/Sparrow, Sidewinder.

Bomb Director AN/ASB-7. Bombing/navigation system for the A3D heavy-attack aircraft. NWC was a participant in the development; IOC was 1956.

Bomb Director AN/ASB-8. For A3J (later designated A-5) aircraft.

Bomb Directing System Mk 9/Mk 10. Mk 9 was the forerunner of the CP-741A. These earlier systems were developed at NWC prior to 1958.

SWAT (Sidewinder Acquisition and Track) System. For F-8/Sidewinder, 1960.

CP-741/A. Weapon-release computer for strike aircraft. IOC was 1966. NWC developed and was lead laboratory.

SEAM (Sidewinder Expanded Acquisition Mode). Contractor design under NOTS direction, to improve target acquisition capability in aircraft employing Sidewinder missiles.

SIDS (Shrike Improved Display System). Display system for Shrike, deployed 1967. NWC was lead laboratory.

TIAS (Target Identification and Acquisition System) AN/APS-117. For Shrike and Standard ARM, effectively used in SEA. IOC was 1969. NWC was lead laboratory.

CP-841/A. Weapon-release computer for strike aircraft. IOC was 1969. NWC developed and was lead laboratory.

TDS (Target Designator System). Later called LST for Laser Spot Tracker. A laser-based system with IOC in 1970. NWC was lead laboratory.

NOGS (Night Observation Gunship). Modification of a Marine Corps OV-10A aircraft to include a FLIR (forward-looking infrared) sensor and a 20-mm gun slaved to the FLIR aimpoint. Successfully demonstrated in combat in 1971. (Later became the OV-10D version of the OV-10 aircraft, which went into production in 1978.)

VTAS (Visual Target Acquisition System). For Sidewinder and Sparrow applications. Contractor-developed with NWC as prime technical advisor. IOC was 1972.

A-7E FLIR System. A light-attack system incorporating a FLIR sensor/display. Entered the Fleet in 1978.

A-6E TRAM. All-weather day/night attack system for the A-6E, incorporating FLIR sensor/display and a laser ranging and designating system. Entered the Fleet in 1979.

ARBS (Angle Rate Bombing System). Originally conceived at NWC. Center was subsequently lead field activity in overseeing contractor development of the system. Used by A-4M and AV-8B aircraft. Introduced into the Fleet in 1983.

AIRCRAFT SOFTWARE AND AVIONICS SYSTEMS, OTHER AIRCRAFT SYSTEMS

AN/ALR-45F. Countermeasures warning and control system, incorporating NWC-designed ALR-67 processor with existing ALR-45 components. Released in 1982.

Drone Aircraft Developments. NWC developed QF-86H/F, QT-38, QF-4; 42 QF-86s by 1983, first flight of QF-4 drone compatible with ITCS, 1983.

OFP (Operational Flight Program) E 120. For A-6 aircraft, 1984.

OFP E 220. For A-6 aircraft, 1983.

OFP NWC-4. For A-7 aircraft, 1983.

OFP NWC-2F. For A-7 aircraft, 1983.

OFP E 230. For A-6 aircraft, in OPEVAL 1985.

AN/ALR-67. Was deployed in its entirety in 1985.

EA-6B/HARM Integration. 1986.

"Assembly 23". Update for the A-4M OFP, complete in 1986.

OFP NWC-5. For A-7 aircraft, 1986.

Omnibus 3 OFP. For AV-8B aircraft, 1986. (Navigation improvements, improved air-to-ground symbology, resolution of display discrepancies.)

OFP for the F/A-18 aircraft. Major enhancement of F/A-18 combat capabilities, 1985-1989. Originally the F/A-18 could carry only AIM-7F/9L missiles and iron bombs. This effort added capability to carry AIM-7M, AIM-9M, Walleye, Harpoon, BLU-80, CBU-78/B, BSU-85/86, PUU-28B, mines, FMU-139, IR/Laser Maverick, Shrike, AN/AWW-9/12/13, SLAM, DSU-30, and AMRAAM. New targeting and avionics capabilities include laser tracker, air-to-air FLIR, AN/ALQ-126.

Memory Loader/Verifier. Primary GSE item to load and verify programs in aircraft and weapon computers. Complete in 1986.

Cheap Night. 1987. Integrated FLIR, night-vision goggles in a TA-7 cockpit with modified cockpit lighting, heads-up/heads-down display. Basis for night capability, which entered the Fleet in AV-8B and F/A-18 in 1989.

Omnibus 4 OFP for the AV-8B aircraft. 1987. (Improved rocket accuracy, even-ripple spacing, Laser Maverick corrections, added BDU-33, BDU-48, corrected all-weather landing system, added engine monitoring system.)

OFP for the AV-8B aircraft. 1987-89. Day attack and night attack. Various additional weapon options.

A-6E System/Weapon Improvement Program (SWIP). 1987-89. Integrated HARM, Harpoon, IR/Laser Maverick into the OFP which became operational in 1988.

FLARES/COUNTERMEASURES

Mk 42/Mk 43 IR Countermeasure Flares. IOC was 1962.

Mk 46 IRCM Flare. Urgent requirement during Vietnam War for a decoy flare, deployed 1967, successfully used in Vietnam.

BRITEYE. A very high intensity flare supported by a hot-air balloon to increase hovering time. NWC was DAPM. IOC 1970.

SOID (Ships Ordnance Infrared Decoy). A modification to a marker flare for Vietnam use. IOC was 1971.

Mk 50 IRCM Flare. Quick response to a Vietnam requirement for an IRCM flare that could be fired from a flare pistol. Credited with saving many lives. Deployed 1972.

EJECTION SEATS, AIR RETARDATION DEVICES

Rocket Catapult Mk 1. Ejection seat for the A-4D and F-104 aircraft. Deployed 1959. NWC was lead laboratory for development.

SEAWARS. Parachute release system for over-ocean utilization. IOC 1984.

SURFACE-TO-AIR WEAPONS

CHAFFROC (Shipboard Chaff Decoy Rocket System). A quick-response effort to meet a Vietnam requirement. IOC was 1967. Quick Bloom Mk 84 CHAFFROC chaff package had IOC in 1970. NWC was lead laboratory.

Seasparrow. Modified Sparrow missile for surface ship launch. NWC designated as Technical Direction Agent by NAVSEA.

Chaparral (MIM-72A). Short-range air-defense system for the Army, based on the Sidewinder AIM-9D missile. IOC was 1970. NWC was lead laboratory for the Army.

Sea Chaparral. Modified version of the Army Chaparral, installed on a number of ships during 1972-1973 as a result of a Vietnam War requirement. This was another quick-response program with NWC serving as lead laboratory.

SURFACE-TO-SURFACE WEAPONS

Rocket-Thrown Line Charge. For clearing minefields. 1,750-pound rocket deployed explosive charge on nylon line. IOC was 1962.

RAP (Rocket Assisted Projectile). To extend the range of existing 5-inch guns. IOC was 1968.

BOMROC (Bombardment Rocket). An extended-range rocket for shore bombardment; for example, in amphibious operations.

Shrike on Board. Shrike missile and associated subsystems were installed on certain ships as a result of an urgent requirement of the Vietnam War. Installed 1972; successfully used; removed when the requirement was terminated. NWC was lead laboratory.

SLUFAE (Surface-Launched Unit, Fuel-Air Explosive). Rocket-propelled system for clearing mines and booby traps by blast effect. NWC was lead laboratory for the weapon portion of the system (the Army was to design the fire control system and launcher).

Universal Arming/Firing Mechanism for ship-launched missiles. 1983.

ASW WEAPONS

(The Pasadena Annex of the Naval Ordnance Test Station, China Lake, was lead laboratory for a number of ASW weapon developments, including Torpedoes Mk 32, Mk 43, Mk 44, and Mk 46 during the 1950s and 1960s. These numerous systems are not listed below, since the Pasadena Annex became, in 1967, part of what is now the Naval Ocean Systems Center (NOSC) and its past achievements may more logically be claimed by NOSC. However, NWC/China Lake participated heavily in development of rocket-propelled ASW weapons, notably in propulsion design, and these systems are noted below.)

Weapon A Rocket with a depth charge payload. NWC was lead laboratory for the development. IOC was 1951 and the system was retired in 1969.

ASROC (Antisubmarine Rocket). A rocket with a torpedo payload. NWC was lead laboratory; China Lake did the rocket portion of the system. IOC was 1962.

Extended-Range ASROC. As implied, a longer-range version of ASROC. Again substantial propulsion work was done at NWC, while the ex-Pasadena Annex had program management responsibilities.

UNIQUE OR SPECIAL APPLICATION SYSTEMS

TIARA. Chemiluminescent systems for various night applications. NWC was active in chemiluminescence studies since 1960 and developed numerous special devices. Example—MARSTICKS, a NOTS/du Pont development in 1962; a luminous marking crayon. NWC's Project CHLOE (Chemiluminescent Light from Oxalate Esters), carried out in collaboration with American Cyanamid, led to the commercial production of Chemlite light sticks, now used in large quantities around the world.

CYCLOPS. Weather-modification device developed by NWC; experimental units employed in Project Stormfury; modified/weaponized hardware saw limited use in SEA. 1960s.

Transit. Ground receiving equipment to support satellite navigation systems. NOTS/China Lake built a number of ground tracking systems, with IOC being 1962. Sponsored by ARPA and directed by APL/JHU.

Deep Jeep. A deep-diving submersible developed at China Lake—first U.S.-built submersible capable of diving to 2,000 feet. IOC was 1965; transferred to Scripps Institute for oceanographic research in 1966. NWC was lead laboratory.

RCCOZ. A rocket ozonsonde developed for NASA, to take observations of ozone distribution at extremely high altitudes. Utilization began in 1965.

Scuttling and Equipment Destruct System. Quick-response project during the Vietnam War, for scuttling vessels carrying sensitive/intelligence materials. 1968.

Radio Firing Device Mk 100 Mod 0. IOC was 1968.

Swimmer Weapon Systems. For the Navy Sea-Air-Land (SEAL) Teams. NWC developed an array of specialized items for the SEAL Teams, including special explosive configurations, limpet mines, rocket launchers, and a Swimmer Delivery Vehicle (SDV) during the 1960s and 1970s, before cognizance over Swimmer Weapon Systems was transferred to the Naval Coastal Systems Center. SDV Mk 7 Mod 6 IOC in 1975.

Fuel Gelling Unit. For producing gelled flame-weapon fuel from AVGAS or JP-5. Prototype in Vietnam in 1968; highly successful. Released to production in 1969.

SUU 53. Cartridge dispenser for weather modification; carries/fires 52 catalyst generators for cloud seeding. IOC was 1974.

North-Finding Module. Man-portable gyrocompass. Approved for service use in 1983.

Laser Leakage Detector. "Sniffing" laser leakage for eye hazard assessment; NWC designed and produced 35 units, 1983.

Multifunction Digital/Video Scan Converter. Designed in 1983, now in production as "Folsom System 5000."

FAST (Floating At-Sea Target). A quick-response task to develop a shipboard-assembled radar target with miss-distance scoring capability. Design completed in 1982.

Directive RF Antenna System. Built on a quick-response basis to meet an urgent requirement of a Naval security facility overseas in 1984. (Minimal contracting, less cost, and far less time than such a development would normally entail.)